

DOCUMENT RESUME

ED 244 810

SE 044 535

AUTHOR Goodman, Harvey; And Others
TITLE A Guide to Establishing a Science/Mathematics Research Program in High School. Experimental.
INSTITUTION New York City Board of Education, N.Y.
REPORT NO ISBN-88315-489-7
PUB DATE 82
NOTE 221p.
PUB TYPE Guides - Classroom Use - Guides (For Teachers) (052)

EDRS PRICE MF01/PC09 Plus Postage.
DESCRIPTORS Biology; Chemistry; Curriculum Development; Earth Science; High Schools; *Laboratory Procedures; Mathematics Instruction; Physics; *Research Methodology; *Research Projects; Research Reports; Science Instruction; *Secondary School Mathematics; *Secondary School Science; *Student Research

ABSTRACT

This guide has been designed to help teachers, supervisors, and administrators set up a science or mathematics research program which should provide students with a set of basic "tools" for use in problem solving situations. The guide is organized into 17 chapters. The first 15 chapters focus on: organizing a research program; recruiting students; using the library; using outside agencies; writing the research paper; teaching laboratory skills; selecting the problem; stating the hypothesis; designing and implementing the research project; recording and interpreting results; stating the conclusion; discussion and implications for future research; presenting the oral report; competing at science and mathematics fairs; and evaluating science and mathematics projects. Chapter 16 provides a sample research project in biology, chemistry, physics, earth science, and mathematics. Chapter 17 provides lists of textbooks and references (for both teachers and students) arranged by science and mathematics topic areas. Many chapters have been divided into separate sections for science and mathematics, with information germane to both areas integrated into the separate sections. However, teachers are encouraged to read both sections to make sure important concepts or suggestions are not missed. (JN)

* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *

A Guide to Establishing

ISBN No. 88315-489-7

● A Science/Mathematics Research Program

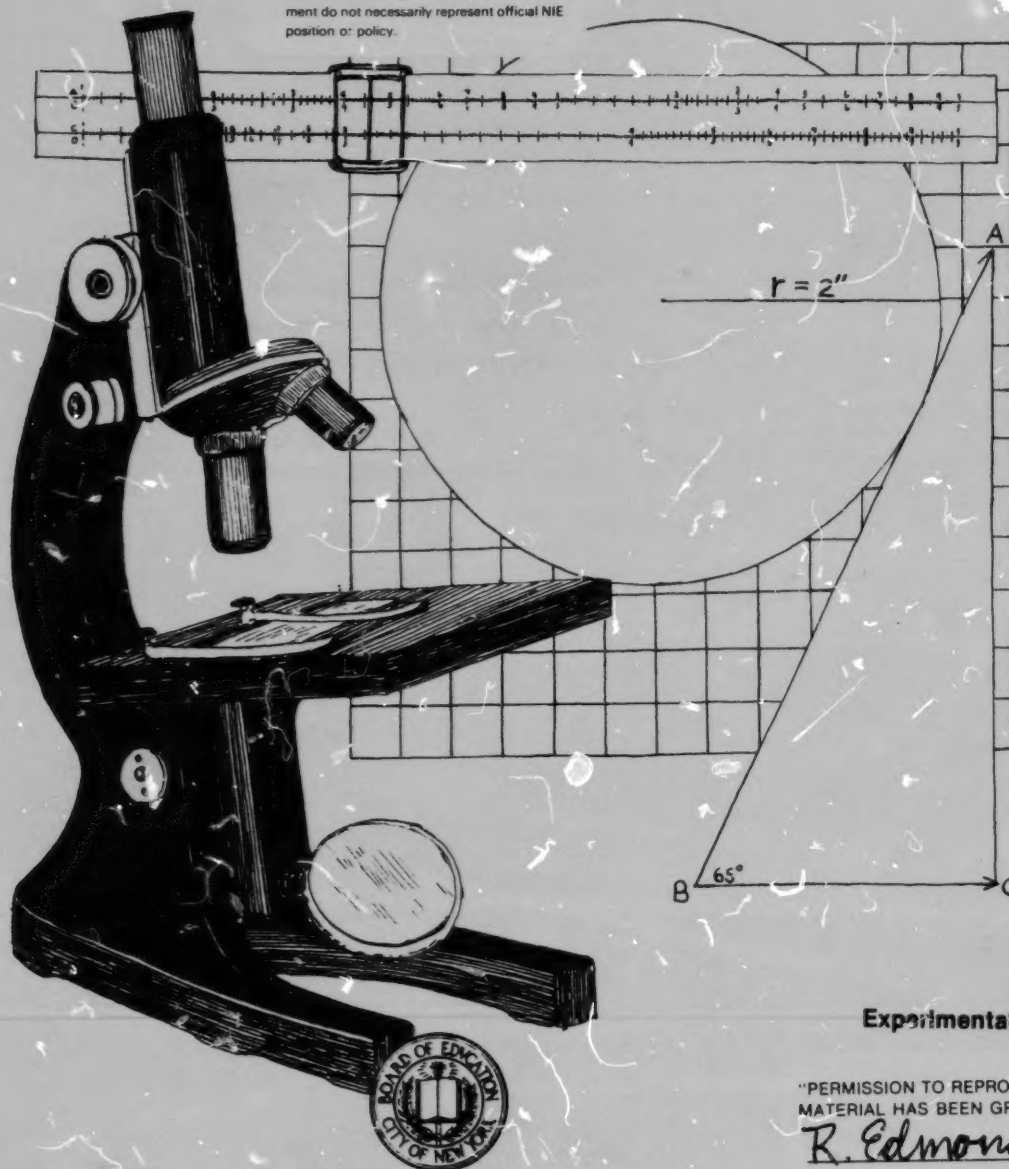
in High School

U.S. DEPARTMENT OF EDUCATION
NATIONAL INSTITUTE OF EDUCATION
EDUCATIONAL RESOURCES INFORMATION
CENTER (ERIC)

✓ This document has been reproduced as
received from the person or organization
originating it.

□ Minor changes have been made to improve
reproduction quality.

● Points of view or opinions stated in this docu-
ment do not necessarily represent official NIE
position or policy.



Experimental

"PERMISSION TO REPRODUCE THIS
MATERIAL HAS BEEN GRANTED BY

R. Edmonds

NEW YORK CITY PUBLIC SCHOOLS
OFFICE OF CURRICULUM DEVELOPMENT AND SUPPORT
DIVISION OF CURRICULUM AND INSTRUCTION

TO THE EDUCATIONAL RESOURCES
INFORMATION CENTER (ERIC)."

New York City Board of Education

Joseph G. Barkan, *President*
Amelia H. Ashe, *Vice President*

Stephen R. Franse
Irene Impellizzeri
Marjorie A. Lewis
Miguel O. Martinez
James F. Regan

Frank J. Macchiarola, *Chancellor*
Richard F. Halverson, *Deputy Chancellor*
Thomas K. Minter, *Deputy Chancellor for Instruction*

Charlotte Frank, *Executive Director*
Division of Curriculum and Instruction

Foreword

A Guide to Establishing a Science/Mathematics Research Program was developed to share, on a citywide basis, the expertise acquired by schools which have developed programs in these fields. While this publication focuses on science and mathematics research, principals/administrators may wish to establish, concurrently, a research program in the humanities and social sciences. Segments of this guide such as Time Schedule for Organizing Your Program, Funding a Research Program, Recruiting Students, Using Outside Agencies, and Using the Library may be helpful for the coordinated planning and administration of research programs in both science/mathematics and the humanities/social sciences.

Materials which relate directly to establishing research programs in the social sciences and humanities are currently being planned. Responses from teachers in all disciplines are invited as an important part of this project. This present experimental bulletin is designed in a loose-leaf format for inclusion of additional materials as these are developed by individual teachers, in various school programs, and by the Division of Curriculum and Instruction.

The individual research project is an exciting mode of learning. The problem-solving skills which students develop will serve them well in their personal and professional future. It is our hope that this guide will become a catalyst in extending research opportunities to ever greater numbers of students in a wide range of disciplines.

Charlotte Frank

Charlotte Frank
Executive Director

Acknowledgments

A Guide to Establishing a Science/Mathematics Research Program in High Schools is a project of the Division of Curriculum and Instruction, Charlotte Frank, Executive Director.

Morris Freedman, Director of the Office of Curriculum Development and Support, provided overall supervision, along with Dr. Anthony Galitsis, Director of Science, and Irwin Kaufman, Director of Mathematics.

The material was written by Harvey Goodman, Assistant Principal, Science, Grover Cleveland High School, Saul Reine, Assistant Principal, Science, Samuel J. Tilden High School, Carl Goodman, Assistant Principal, Mathematics, Benjamin Cardozo High School, and Mark Saul, mathematics teacher, Bronx High School of Science.

The final editing and production of the bulletin were the responsibility of the Editorial Production Unit (Alaire Mitchell, Unit Head). Sarah Corbin supervised the word processing, assisted by Steven Goodman, Ressie Della Rosa, and Oi M. Lee. Nancy Levine, teacher at John Jay High School, copyedited the manuscript. Maurice Bleifeld, Principal (retired), Martin Van Buren High School, reviewed the manuscript for technical accuracy and sensitivity.

Artwork and cover design by Glenn Casper, science teacher, JHS 232 (District 18). Additional drawings by Oleg Niestadt. Mechanicals by Conrad Nunnally.

Book design, art concept, final editing, and coordination of the production, Maureen Maguire.

Table of Contents

Foreword	iii
Acknowledgments	iv
How to Use This Bulletin	vii
Why a Research Program?	viii
Questions and Answers	x
 CHAPTER 1. Organizing a Research Program	
Personnel Requirements	3
Time Schedule for Organizing Your Program	5
The Physical Plant	6
School, Department, and Public Libraries	7
Materials and Equipment--Science	10
Materials and Equipment--Math	12
Funding a Research Program	13
Model Programs	15
 CHAPTER 2. Recruiting Students	
The Need for Recruitment	25
Student Qualifications	26
Specific Techniques in Recruitment	27
 CHAPTER 3. Using the Library	
Obtaining Information	35
Gathering and Processing Information	35
Literature Research Skills	36
Student Guide for Organizing Readings for the	
Research Paper	42
Organizing a Library Lesson	43
Use of the Library for Mathematical Research	43
 CHAPTER 4. Using Outside Agencies	
Part I --Science	45
Part II--Mathematics	53
 CHAPTER 5. Writing the Research Paper	
Part I --Science	57
Part II--Mathematics	69
 CHAPTER 6. Teaching Laboratory Skills	
Introduction	79
Laboratory Safety Guidelines for Students	80
Teacher Checklist for Structural and Safety	
Features in the Laboratory	81
Laboratory Skills Needed for Research in Biology	82
Laboratory Skills Needed for Research in Chemistry	86
Laboratory Skills Needed for Research in Physics	86
 CHAPTER 7. Selecting the Problem	
Part I --Science	87
Part II--Mathematics (Teaching Problem-Solving Skills)	99

CHAPTER 8. Stating the Hypothesis	
What Is an Hypothesis and How Does It Assist in Experimental Design?	117
Formulating the Hypothesis	117
Modifying the Hypothesis and Planning for Further Investigations	118
CHAPTER 9. Designing and Implementing the Research Project	
Part I --Science	121
Part II--Mathematics	131
CHAPTER 10. Recording and Interpreting Results	
Part I --Science	139
Part II--Mathematics	147
CHAPTER 11. Stating the Conclusion	
Introduction	157
What is a "Conclusion"?	157
Evaluating the Conclusion	157
CHAPTER 12. Discussion and Implications for Future Research	
Discussion	163
Implications for Future Research	163
CHAPTER 13. Presenting the Oral Report	
Part I --Science	165
Part II--Mathematics	171
CHAPTER 14. Competing at Science and Mathematics Fairs	
Part I --Types of Competitions	175
Part II --Science	161
Part III--Mathematics	189
CHAPTER 15. Evaluating Science and Math Projects	
Evaluating Science Projects	195
Research Evaluation Form	196
Evaluation of Mathematics Projects	199
CHAPTER 16. Sample Science and Mathematics Research Projects	
Sample Research Problems in Biology	203
A Sample Research Problem in Chemistry	204
A Sample Research Problem in Physics	204
A Sample Research Problem in Earth Science	205
A Sample Research Problem in Mathematics	206
CHAPTER 17 Texts and References	
Part I --Science	209
Part II--Mathematics	239

How to Use This Bulletin

This guide has been designed to help teachers, supervisors, and administrators set up a program in science and mathematics research. The teachers who worked on this document have been involved in every facet of creating and implementing science-mathematics research programs in our schools over the past ten to twenty years.

The course should provide students a set of basic "tools" that can be used in the highest of cognitive skills--problem solving. As students acquire these problem-solving skills, the course will be transformed from a group learning situation to an independent study group. The instructor and the student will begin to learn new specific information together. The instructor will bring experience in dealing with similar problems to the student, and the student must be ready to devote time, energy, and a desire to learn in this new type of environment. The student-teacher bond that develops will allow both to grow. If a student has learned to work independently and the teacher has learned how to "push," demand, encourage, support, and teach, most students who participate in a research program will profit from the experience. The skills they acquire will play a much more vital role in their future than any Westinghouse Award or science fair medal. Indeed, for those students who are conscientious and a little lucky, the awards will be there. Any student who has lived through a science research program knows that the teacher has given above and beyond the call of duty. It is the belief of every member of this committee that student success in a research program is directly proportional to the teacher's willingness to provide equal "sweat equity."

Any teacher who elects to set up and teach a research course will profit from the experience. This guide was designed to help the persons involved avoid some of the pitfalls encountered by those who set up research programs in the past.

Each science or mathematics research program must be tailor-made to meet the needs of the students with whom the instructor will be working. The background philosophy of the instructor will play a vital role in the eventual shape of the research course. Each instructor will evolve his or her own course of study over a period of time.

The information contained within this guide must be expanded upon, modified, and reshaped when the teacher implements the program.

Portions of this guide have been divided into separate math or science sections. It is important to note that this dichotomy is not absolute. Thus, information germane to both areas is integrated into the separate sections. The teacher of either discipline should read both the mathematics and science sections to make sure important concepts or suggestions are not missed.

Why a Research Program

Introduction

When a teacher or supervisor proposes a mathematics or science research class, administrators will probably ask "Why?" Consequently, every teacher must come armed with answers. A principal or an assistant principal in charge of supervision is not likely to give up a precious 0.4 or 0.2 of a unit to a program that is tailor-made for small-group situations unless the school and students participating will profit greatly from the experience.

Superintendents and principals are always looking for items that will enhance the district's or school's image. Student participation in a science or mathematics research program can help in this area. Aside from the obvious -- being prepared to enter science contests -- each time students and/or their parents talk about the "special research program," a message is going out into the community. "Our high school has something good going on." Parents may want their children involved, and the choice of going to a special high school or the local high school might hinge upon the local high school's offering of a science or mathematics research program. Many Westinghouse and Science Fair awards are won by students in schools other than special high schools with entrance examination requirements.

In addition, when research program participants visit local and college libraries, they are carrying the name of their high school with them. Thus, twenty to thirty "advertisers" are sent out into the community to improve the high school's image. The participating students and the school have thus established a symbiotic relationship. Students profit from the program and the school profits from the students' participation.

A science or mathematics research program can have positive effects on the entire student body. If a Tilden student wins a Westinghouse award, many students in the school will identify with this. Students may have a sense of pride and hope that, "If one of my peers can do well, if I work hard enough, I can do the same."

When the assistant principal goes to feeder schools to encourage students to attend the local high school, students participating in the science or the mathematics research program can accompany him or her and do more to encourage junior high school students to attend the local high school than any adult sales pitch.

Within the high school science or mathematics program there is a need for guest speakers in regular and special elective classes. Students participating in a research program can function in this role once their research projects have been completed. The researcher profits from the experience of "presenting" and the audience profits from the knowledge that one of their peers could accomplish so much.

Moreover, students involved in a science research program can serve as the nucleus of the science department's laboratory squad. As members of the lab squad, trained in maintaining specific organisms or skilled with many laboratory techniques, these students can render invaluable service to the school. For example, the research class could provide a plethora of organisms ordinarily purchased by the school's perishable fund. In addition, the many solutions or calibrations of equipment needed in chemistry and physics classes can be done by the student researchers. This will eliminate the need to purchase specially prepared solutions or call in service-repair people to service the school's equipment. The school is providing the "researchers" with an opportunity to practice what they have been taught. Once established, the science or mathematics research program and the school have evolved into a classic example of synergism. Both are accomplishing something much better than each could do individually.

The science or mathematics research class could infuse "new life" into the teacher who elects to become involved in the program. The problem of "teacher burnout" can be eliminated or reduced if a person feels involved in a new and exciting activity. In addition to a new set of challenges in the research program, the teacher's enthusiasm will carry over into the "regular class" that the person teaches. Thus 150 students may benefit from the energies of the "revitalized" teacher.

The chain reaction of the benefits, for the participating students and the school, of the establishment and maintenance of a science research program go beyond the participating students. All members of the school profit. Once a principal or assistant principal realizes this, the research program is in the school to stay.

Questions and Answers

Overview for Planning the Science/Mathematics Research Program

1. Why should we pursue a science/mathematics research program?

Because it:

- a) enhances one of the major goals of science education: teaching science as inquiry.
- b) allows students to think creatively and to work independently.
- c) provides recognition for the school community and becomes a "show-case" for displaying academic excellence.
- d) encourages teachers to be part of a challenging situation that utilizes their professional training to the utmost.
- e) trains students to be part of a laboratory squad.
- f) improves the students' chances for being accepted into major universities and colleges.
- g) motivates students from feeder schools to select admission into your school.

2. What should be done to organize the program?

- a) The philosophy and goals of the program should be clearly stated. Courses that reflect this philosophy should be designed. Staff that support the ideals of the program, and are willing to put in the appropriate effort, should be recruited.
- b) Whenever possible, students should be programmed for a double period, so that laboratory skills and problem-solving techniques may be properly developed.
- c) Plans should be made to provide adequate laboratory and/or computer facilities.
- d) Funding should be anticipated in order to determine the extent of student projects.
- e) Contacts should be made with local hospitals, universities and professional organizations to permit student access to their laboratories and libraries.
- f) An interdisciplinary approach should be coordinated so that students may avail themselves of the special skills found in each discipline.

- g) Active recruitment should be planned both for incoming students and for students presently enrolled at the school. Recruitment may take the form of interclass visitation, special orientation programs, letters to parents, and/or articulation with feeder schools.
3. What are the steps that should be followed in guiding students to the selection and implementation of a project?

Essentially, instructors utilize the scientific method in guiding their students. Briefly the steps to be taken are:

- a) Selecting a problem.
- b) Locating and summarizing appropriate literature.
- c) Stating the hypothesis.
- d) Designing the experiment, and learning all of the needed laboratory skills required.
- e) Collecting and interpreting the data.
- f) Discussing the results and stating the conclusion.

Guest speakers, class trips, and various college/university programs will help to motivate the student.

4. What can the student do with the research paper once it is completed?

A well-written research paper represents many hours of effort, and will provide the student with a great deal of recognition that will enable him or her to plan for a productive future. A number of opportunities for recognition are:

- a) The New York City Science fairs
- b) The Otto-Burgdorf Congress
- c) The Westinghouse Science Talent Search
- d) S.E.E.R.
- e) Numerous mathematics fairs.

In addition, submitting a copy of the research paper as part of the college application will improve the student's chances for admission to the school of his or her choice.

1.

ORGANIZING A RESEARCH PROGRAM

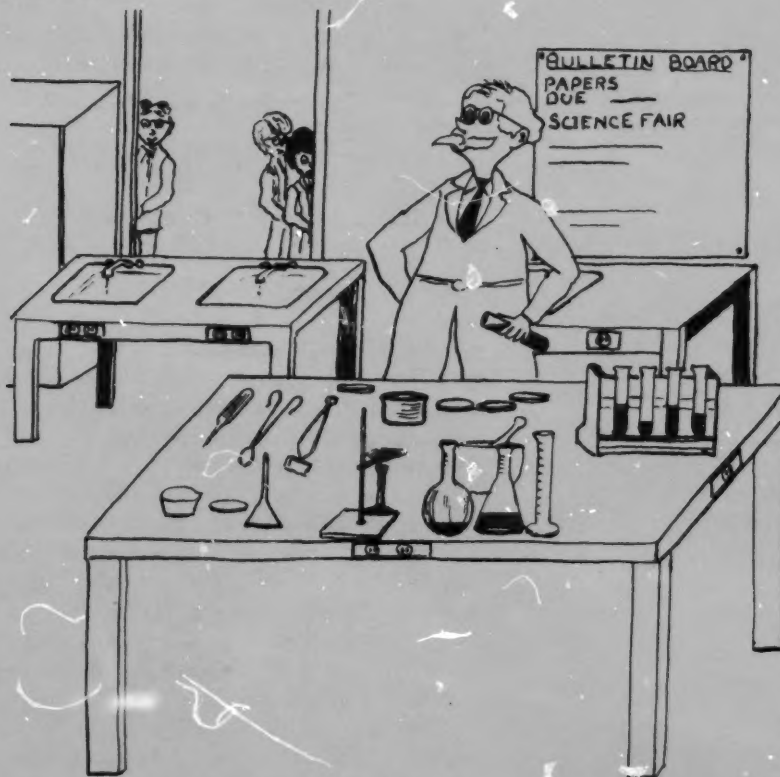


Personnel Requirements

The ideal situation in mathematics and science would be the incorporation of research problems within the curricula. Indeed, the movement toward teaching science by inquiry or by investigative methodology may very well stimulate interest in science/mathematics research. However, if a concerted effort is not provided to guide the specific implementation and development of science projects, the effort in the classroom will yield very sparse results.

The Teacher

Individuals who are interested in instructing a research class should be aware of additional responsibilities inherent in such a program. The items below should be considered.



1. Attendance at Junior Academy functions and various professional meetings in order to keep abreast of new programs and opportunities is desirable. Such involvement also provides a model to encourage your students' participation in conferences and seminars.

2. Reviewing term papers can, and will, occupy many hours before and after the school program. Many "Westinghouse Science Talent Search" reports average between 50-80 pages. Multiply this times the number of students in the class and you will quickly see the tremendous amount of work involved. In addition, there are demands for an outstanding interpersonal relationship with the students.
3. Academic preparation is assumed within the requirements for the license. However, continued professional training (for example, reading current literature, attending professional seminars and conferences, registering for college or in-service courses) is vital for this highly specialized program.
4. The staff member must be sincerely interested in each individual student. He or she must express satisfaction when a breakthrough results, and provide empathy and encouragement when desired outcomes are not attained. Above all, the staff member must be patient and understanding.

The Science Research Coordinator

Clearly there are a large number of requirements encountered in a science research program. The ordering of supplies, maintaining records for each student, and grading papers are but a few of the chores that must be accomplished. Some schools have assigned a teacher as science research coordinator, and have provided that teacher with allotments that range from teaching one less class (a 0.2 allotment) to being excused from a homeroom or other administrative assignment. A viable research program cannot be conducted or coordinated by a staff member carrying a full teaching and administrative load. However, each school is unique and each program highly individual. Thus, the final decision in terms of assignment must remain, and correctly so, with each school's principal.

A fear common to many teachers is that they must know everything about the research conducted by their students. Be advised of the impracticality as well as the impossibility of this goal. Students, through their in-depth research, will attain a knowledge beyond their teacher's individual training. When that happens, the program is successful. Teachers must be willing to learn and be part of the process with their students.

The Guidance Component

As the program develops, it would be well to arrange for the assignment of one of the two guidance counselors, with the responsibility of programming the students in the research program. Concentrating the programming with a single counselor has many benefits.

1. The counselor will be familiar with the unique needs of the program.
2. Students selected for the program will have their progress closely monitored for the duration of their high school program. Thus students who are not achieving to capacity can be quickly identified and appropriate remediation provided.
3. Staff members can discuss student and programming difficulties with a single advisor rather than with numerous counselors.

The guidance personnel may assist in providing career guidance workshops. Indeed, a counselor may even invite guest speakers or organize class trips in order to accomplish this vital service and so become an additional resource for the program.

Time Schedule for Organizing Your Program

- | | |
|--------------------|--|
| February-
March | <ol style="list-style-type: none">1. Forward brochures describing your program to feeder schools.2. Invite guidance and administrative staff to your school for an orientation. |
| April | <ol style="list-style-type: none">1. Select staff.2. Follow-up letter to feeder schools. |
| May-
June | <ol style="list-style-type: none">1. Review incoming students' applications.2. Letter to parents advising them that their child has been admitted to the program, and inviting them to a parent-student orientation meeting.3. Parent-student orientation meeting. |

NOTE: Often neglected as resources for student recruitment are the students who are presently enrolled in your school (ninth and tenth graders). Review past performance and solicit teacher recommendations in order to include this group within your organizational scheme.

The Physical Plant

A mathematics or science research program may be thought of as a school-within-a-school. Therefore, such a program has certain physical requirements.

Bookshelves and file cabinets are a necessity. One of the basic sources of references and ideas is a file of old student research papers. Many printed references, as well as backissues of journals, need to be kept handy for students to browse through or refer to. A bulletin board should be reserved for the research class, announcing due dates for papers, mathematics team contests, mathematics and science fair schedules, and schedules for individual meetings with the research advisor.

For the science research class, a separate laboratory room should be made available. The room should have workbenches (two to four students each). Each workbench should have an electrical outlet (120 volts) a sink, and drawers for storage. Microscope and equipment storage cabinets must be made available. A fume hood must be in the labs to facilitate the safe handling of toxic, flammable, or radioactive materials. A lecture classroom should be set aside for lessons that do not require lab facilities. A balance room might be set up for the storage and use of analytical balances. This room will limit the movement of these sensitive instruments. Access to the roof area (for environmental experiments such as those for monitoring air pollution) as well as access to the science equipment and storage areas should be provided.

If a separate lab room cannot be obtained, provisions must be made for the storage of all special equipment and student project work. The laboratory specialists and their lab squads should be trained to assist in the handling of science research materials and equipment.

Mathematics researchers will at some point find that they need access to computer facilities. Most schools have some computer equipment, which is used for an introductory computer science or computer literacy course. Generally, students will not need more than such equipment for research purposes. It is important, however, that students doing research be able to use the machines whenever they have free time without disturbing the day-to-day workings of the computer classes. This may be accomplished by having the computers in a separate laboratory room shared by research students and students in other classes. Or, the machines may be put into the mathematics department office. Small machines may be kept on carts, so that they can be moved to any convenient spot.

School, Department and Public Libraries

The science textbook that students are now reading is most likely outdated in much of its content. The myriad problems resulting from mathematical theorems cannot be contained in any single text. Thus, exploring a problem in mathematics or science requires access to numerous texts, periodicals, and a host of resource materials. The use of the library is so vital to this program that it is considered in a separate chapter. A list of those essential items that should be available in your school library follows.

1. College mathematics and science textbooks
2. Encyclopedias - (Britannica, Americana, McGraw Hill-Science and Technology)
3. Reader's Guide to Periodical Literature
4. Science and mathematics periodicals
5. Vertical files for a variety of subjects
6. Microfiche storage capability
7. Other reference books including biological or mathematical abstracts



The department office is an ideal location for storage of resource text material. Students and staff will have a tendency to use office storage items more frequently than those stored in the library. The use of a department office has a secondary beneficial spin-off in that it establishes a closer commitment and involvement with the department.

Funding is always a problem. Where can I get the monies to secure the publications needed? You certainly should request that the library utilize part of its annual allotment towards the purchase of specific periodicals such as: Scientific American; Science; Omni; Science '80; American Mathematical Monthly; Mathematics Magazine; The Mathematics Teacher; etc. The list is literally endless and a listing of periodicals should be available with the librarian. In addition, libraries may purchase college level reference books. All publishers have a separate college catalogue, and most will permit examination of texts for usability prior to purchase. The use of college and university libraries is vital. (More detailed aspects of this topic will be discussed later.) Most college libraries will permit students in the program to read and review publications but not to withdraw them. Encourage students to photocopy as needed. It is advisable that the research coordinator check with the college librarian regarding specific policies for use of their library. A partial listing of public and specialized libraries follows.

Public Libraries

- . The New York Public Library/Main Branch 790-6161
Fifth Avenue at 42nd Street, New York 10018
- The Mid-Manhattan Branch 790-6161
8 East 40th Street, New York, 10016
- . The Brooklyn Public Library/Main Branch 636-3111
Grand Army Plaza, Brooklyn, 11238
- . The Queensborough Public Library/Main Branch 990-0700
89-11 Merrick Blvd. Jamaica, 11432

Specialized Libraries

- . The American Institute of Physics
Niels Bohr Library 661-9409
335 East 45 Street, New York 10017
- . Chemists Club Library 532-7649
52 East 41 Street, New York 10017
- . The Library of the American Museum
of Natural History 873-1300
Central Park West at 79th Street,
New York 10024
- . The New York Academy of Medicine
Library 876-8200
2 East 103rd Street, New York 10029
- . The United Engineering Center
Library 644-7500
345 East 47th Street, New York 10017

In addition numerous professional organizations maintain very specific libraries:

- . The American Cancer Society 371-2900
777 Third Avenue, New York 10017
- . The Horticultural Society 757-0915
128 West 58th Street, New York 10019
- . The National Audubon Society 832-3200
950 Third Avenue, New York 10022
- . The National Society to
Prevent Blindness 684-3505
79 Madison Avenue, New York 10016
- . The New York Aquarium 266-8500
West 8th Street and Surf Avenue, Brooklyn 11224
- . The New York Botanical Gardens 220-8751
Webster Avenue at 200th Street, Bronx 10458
- . The New York Zoological Society 220-5124
185th Street and Southern Boulevard, Bronx, 10460
- . The Parapsychology Foundation 751-5940
29 West 57th Street, New York 10019
- . The Revlon Research Library 824-9000
945 Zerega Avenue, Bronx, 10473

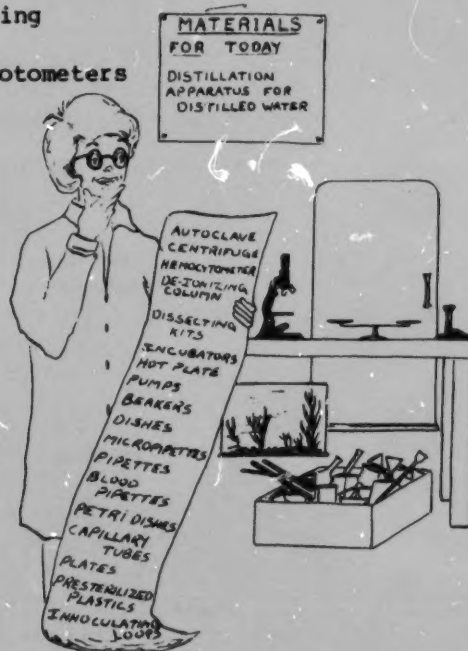
For further information and a more detailed description of each of these libraries, contact the Junior Academy of the New York Academy of Sciences at 212-838-0230.

Materials and Equipment — Science

The following is a listing of suggested materials and equipment that are needed to set up a viable research program. Some of the items listed may not be available in the school at present; but a creative teacher can work around the missing items until such time as the items can be purchased, built, or borrowed.

General Equipment

autoclave or pressure cooker
aquarium tanks 2.5-10 gallons
balances - analytical, triple-beam
burners - Bunsen, Fischer
centrifuge
counting chambers (hemocytometers)
de-ionizing column or distillation apparatus for distilled water
dissecting kits
environmental chambers - to maintain 21-23°C
incubators (37°C)
inoculating loops and needles
magnetic stirrer and hot plate
microscope, oil immersion
microscope, dissecting
mortar and pestle
needles, hypodermic (various gauges)
pipette washers
polyethylene plugs - test tubes and flasks
pumps, aquarium
refrigerator
rubber stoppers and tubing
rulers (metric)
spectronic 20 spectrophotometers
test-tube racks



Glassware

beakers, (Pyrex or Kimax) 50, 100, 250, 500, 1000 ml
bottles, storage
dishes, culture 2, 4, 10 in round
flasks, Erlenmeyer (Pyrex or Kimax) 50, 125, 250,
500, 1000 ml
funnels
glass rods
glass tubing (8 mm)
graduated cylinders - 10, 25, 50, 100, 250,
500, 1000 ml
microscope slides and cover slips
micropipettes - 5, 10, 20, 50, 100, 200 ml
pipettes 1, 2, 5, 10, 25 ml
pipettes, blood (red)
plates, Petri glass or presterilized plastic
test tubes, 13 x 100 mm, 22 x 175 mm
tubes, centrifuge 15 ml, 60 ml.
tubes, capillary non-heparinized

Chemicals

It is probably not necessary to set up a separate chemical supply shelf for the research class. Many of the solutions students will prepare require reagents that are most likely in the school. As time and the program progress, there will be a need for specific inorganic and organic compounds. These compounds should be purchased by the research program and stored in the research lab. Most scientific supply catalogues should be adequate for these needs. If additional specific organic compounds are required, a catalogue such as the Sigma Catalogue should meet this need.

Organisms

Living organisms can be purchased from one of the many biological supply companies. It is often wise to purchase the organism and the specific medium needed for its maintenance. Do this for "complex" media such as nutrient agars, Drosophila media, and complex media needed to maintain unique organisms, for example - tobacco and tomato hornworms. The culturing of algae and protozoa can be successfully accomplished using in-house media preparations.

Other Material

To plan for other materials think of what is needed to set up and maintain a house or apartment. Then list the 25-50 most important items. These are the "other materials." The aluminium foil, detergents, light bulbs, masking tape, etc. However, there will always be items missing initially. After about a week, the list will begin to grow exponentially.

Materials and Equipment — Math

Most of the material necessary for mathematical research projects is printed matter. A list of these basic reference books and journals can be found in the appendix. Research papers written in past years may also prove useful.

Software packages, making computer capabilities accessible to the students, should be made available. These should include high-level language such as BASIC or FORTRAN. A word processing package is helpful in writing the final paper. A statistical software package may be useful for students whose research involves statistical inference.

Teacher's Notes



Funding a Research Program



After reading the listing of materials in this document, and then completing an inventory of the schools supplies, one should now ask: "Who will supply the funding for all the material we don't have?" This might seem to be an insurmountable task, but it is not. The first thing to be done is the preparation of two lists: Immediate Needs and Long Range Needs. Once this has been completed the program can get off the ground with a relatively small investment.

Student Purchases - Students may have to purchase organisms and maintenance equipment for these organisms for home use. If students have made these purchases, they may wish to donate some of these materials to the research program.

Special Fund Raisers - Funding drives may be held as long as they are done in accordance with Board of Education guidelines. Such activities as the sale of specialty items - calendars, holiday decorations, candles, maps, plants, candy, pens and pencils - can bring in significant quantities of money for the research program.

Perishable Funds - Each year every high school is given an allotment to defray the cost of perishable items. It is the job of the science department administrator to meet with the principal and assistant principal (administration) to secure funding for the research class. Organisms, media, chemicals, disposable glassware, Petri dishes, and pipettes can be purchased from this fund.

Club Funds - Every research program should have an after-school club activity. It is very difficult to run a successful research class without such a club. The time demands required to produce a successful science research project are so great that it is impossible to complete one's work during the normal school day. The club activity helps provide some of the time needed to allow students to work in school. All club activities are funded via the high school's Student Government Organization. Once the club's charter has been approved by the Student Government Organization, the club may apply for funding.

Donations - Parents' associations, religious groups, professional organizations, large corporations, and local business groups can all be approached to donate funds for the science research program. It is suggested that students accompany all school personnel when fund-raising appeals are to be made at any of these organizations. The probability of being successful in these drives is much greater than one might think.

Grant Writing - Grants are available from federal, state, local and private sources. It is suggested that the science research teacher contact the appropriate Board of Education personnel to get into the area of grant writing. This is a very time-consuming activity. Therefore, it must be done correctly in order for the effort to produce results. Guidance from experts is absolutely necessary for success. Local congressmen, senators, state and city legislators can be contacted to provide "leads" to the available funding.

Hospitals and Colleges - Liaisons can be set up with local hospital and colleges to provide students with opportunities to do volunteer work in research laboratories. This is not a direct source of funding, but it is a method of making materials and equipment available to students.

Model Programs

Each school must tailor a program to meet the unique needs of the school, the student body, and the teaching staff. If one were to survey all the schools that have set up a research program, each would be different, yet similar. The following is an example of one such program set up at Grover Cleveland High School:

BIOLOGICAL AND PHYSICAL SCIENCE FOR GIFTED AND TALENTED STUDENTS

The goals of the program designed for Grover Cleveland High School are to:

- . provide enriched science curricula;
- . provide for extracurricular programs including: affiliation with the Junior Academy of Sciences and Future Scientists of America;
- . provide for career guidance through the use of seminars, guest speakers, and departmental trips;
- . encourage pupil participation in the class and in the evaluation of their departmental programs;
- . create student awareness and sensitivity to environmental problems and other contemporary scientific concerns;
- . develop skills in finding, reading and interpreting science literature;
- . encourage laboratory activities that are investigative in nature and provide for student inquiry;
- . allow for the use of community resources when appropriate;
- . show students how the applications of the basic principles of science have contributed to the intellectual development of mankind and serve an important role in attacking society's problems.

Implied in this sequence is the development of student identity, self awareness and confidence. This will enable the individual to assume a leadership role within the school community and to make appropriate decisions regarding his or her future.

Course Sequence for Science Honors

FIRST YEAR

1. Laboratory Techniques I, II (programmed as a single class, meeting for a double period each day)

Students are provided with experiences in observation, forming hypotheses and testing hypotheses through experimentation.

2. Biology I, II (Honors Regents) (programmed as a single class, meeting for a double period each day)

This New York State Regents Biology course is supplemented with many open-ended laboratory experiments.

SECOND YEAR

1. Science Research Class I, II. (five periods per week)

Students are provided with the opportunity to develop and carry out a science project of their own choosing. Under the guidance of the science departments, these projects are entered in various local and national science fairs and contests. Further opportunity is provided for independent research and affiliation with local colleges, universities, and hospitals.

2. Chemistry I, II (Honors Regents) (six periods per week)

New York State Regents chemistry course.

THIRD YEAR

1. Westinghouse Science Talent Search Program I, II
(five periods per week)

Students are directed to submit a paper on their research project for entry in the International Westinghouse Science Talent Search Program. Juniors and seniors are encouraged to continue their research and to assist new students in the development of research skills.

2. Physics I, II (Honors Regents) (seven periods per week)

New York State Regents Physics course.

3. Advanced placement biology

4. Advanced placement chemistry

Elective Courses in Biological Science

To develop in high school students an absorbing and continuing interest in the biological sciences requires an effective means of instruction. Moreover, it is important that the program provide dynamic experiences which will enhance the development of an understanding and appreciation of the nature and meaning of basic biological concepts.

Our elective subjects offer this philosophy by providing an atmosphere of biology-in-action-an atmosphere in which students develop the necessary techniques for a scientific approach to the study of a problem through active involvement in its solution. Using living materials and the element of experimentation in their study, students come to an understanding of how the sensitive and delicately balanced organization which we call life operates within equally complex surroundings.

ADVANCED PLACEMENT BIOLOGY: (eight periods per week)

Students who have successfully completed Biology 1, 2 and Chemistry 1, 2 are encouraged to select Advanced Placement Biology during their senior year. This course is designed to prepare students for the National Advanced Placement Examination, where they may receive up to 8 credits for advanced college standing in the area of biology. A minimum of six recitations and two laboratory periods are scheduled each week. Topics

include: anatomy and physiology, genetics, embryology, ecology, botany, zoology, taxonomy, conservation and contemporary problems in biology. Laboratory experiences include: fetal pig dissection, various microscope and anatomical model and structural analysis, qualitative and quantitative bio-chemical testing, and a variety of field trips. College level textbooks are supplemented by articles from science journals such as Scientific American and Science. Guest speakers and career guidance are provided throughout the year.

BOTANY: PLANT CARE - HORTICULTURE

Included are: study of the structure of various groups of plants; topics involving indoor plants and gardening; field trips, collections, and experiments in hybridization; students' laboratory work involving the culturing of a variety of plants, and instruction in "dried flower" arrangements.

ZOOLOGY: ANIMAL HUSBANDRY

Study of different kinds of animals on an evolutionary and comparative basis. Includes dissection, field trips, and animal husbandry and care. A zoo is maintained by students.

HUMAN PHYSIOLOGY

Detailed study of the structure and function of vertebrates with emphasis on humans. Laboratory experiments in which principles applicable to vertebrate physiology are conducted throughout the term.

The following courses are offered in accordance with student interest and enrollment:

GENETICS

When sexual reproduction occurs, both parents contribute a copy of a chemical code that controls the development of the offspring. Each new organism resembles its parents in some ways yet differs in others. What chemical code controls this influence? The answer lies in the study of cells and their chromosomes. The branch of biology that deals with heredity is called genetics. The experimental phase of this course involves the determination of basic genetic concepts through the use of culturing techniques involving the fruit fly (Drosophila) and bacteria.

ECOLOGY

A study of the relationships and reactions between living things and their environment. Field trips and experimentation are part of the course of study. School and community beautification projects are undertaken.

MARINE BIOLOGY

A study of the structure and function of organisms which live in the oceans. Students collect various kinds of specimens and learn to maintain them in the laboratory.

PSYCHOBIOLOGY

A program that focuses on learning behavior and psychological disorders. Controlled animal experimentation, hospital visitation, guest speakers and case studies are focal points of this course.

Physical Science Electives

CHEMISTRY - One year (six periods per week)

This course is intended for students who plan to go to college. It is a Regents subject concerned with the "how" and "why" of changes in matter. For this high level laboratory course, ninth year mathematics is a prerequisite. Tenth year mathematics is suggested and preference is for those students taking eleventh year mathematics. For those interested in science or health fields this course is nearly always required.

EARTH SCIENCE - One year (six periods per week)

Was the earth always as it is now? Is it changing now? How? Answers to these and other intriguing questions are found in this Regents course. Students should have had one year of algebra and a year of science. Demonstrations and lab work are an integral part of the course.

PHYSICS - One Year (seven periods per week)

This course is excellent preparation for all college-bound students who are interested in the science or health fields. It is a Regents course with tenth year mathematics required and eleventh year mathematics strongly recommended as a corequisite or prerequisite. The average academic student, with application, can do well. Topics covered are: sound, light, heat, electricity, nuclear physics, mechanics and motion. An understanding of physics can be of great value to the academic students, even in such diverse fields as law and journalism.

ASTRONOMY (One year)

No need to wait until the year 2001! In this course the student can journey to the sands of Mars and the moons of Jupiter; the meteors and comets and the distant stars and galaxies; the black holes and white dwarfs, pulsars and quasars. Students can discover their past and probe their future with the astronomers.

FLIGHT SCIENCE - One and one-half years

This course is designed for those who are either casually or seriously interested in learning how an airplane flies. It's given with the aid of a flight simulator. Official FAA films are used to help students earn a pilot's license. The mechanics of flight, engine operations, weather systems, map reading, navigation, medical factors of flight, and radio communications are but a few of the topics covered. Students should have had at least one year of science and a year of mathematics

ADVANCED PLACEMENT CHEMISTRY (eight periods per week)

The Advanced Placement Chemistry course is designed to be the equivalent of the general chemistry course usually taken during the first college year.

Students in such a course will attain a depth of understanding of fundamentals and a reasonable competence in dealing with chemical problems. The course contributes to the development of the students' abilities to think with clarity and logic. The college course in general chemistry differs qualitatively from the usual basic secondary school course in chemistry with respect to the kind of textbook used, the topics covered, the emphasis on chemical calculations and the mathematical formulation of principles, and the kind of laboratory work done by students.

Model Program Adopted from Cerdozo High School

MATHEMATICS RESEARCH PROGRAM FOR GIFTED AND TALENTED

First Year

1. 10th year or 11th year Honors or Extra Honors
2. Mathematics Research I and II

Second Year

1. 11th year or 12th year Mathematics
2. Mathematics Research III or IV

Third Year

1. 12th year Mathematics and/or
2. Advanced Placement Mathematics (B.C. Calculus)
3. Mathematics Research V and VI

Elective Courses in Mathematics

1. Computer Mathematics
2. Statistics
3. Independent Studies

The model program for a Mathematics Research Program parallels the Science Research since the student is required to take a mathematics research class in addition to his or her regular honors or super-honors mathematics class. In addition, the student is required to meet individually with his or her mathematics research teacher on prearranged dates as his or her paper enters various "draft" stages. Students who have completed an accelerated mathematics program can elect to take independent study course at local colleges.

Programming the student for electives in addition to the research courses offers some difficulties. Some students will have as many as three mathematics courses during a term. It should also be mentioned that many mathematics research students do not take a formal computer course. They may be able to learn programming in conjunction with their investigations. Occasionally the mathematics research teacher will spend a small amount of time acquainting the students with the computer facilities and with "self-learning" materials involving programming. Experience has shown that in a very short period of time the students are able to use the computers and produce worthwhile programs associated with their projects.

The statistics course elective offered to students in their junior year plays an important role. It can be a support to the science research program. It can generate curiosity and investigation into the field of mathematical statistics. And it can serve as a "tool" for students interested in research into the social sciences. Combined with computer hardware and statistical software packages, such a course can enable an interested student with an astute advisor to make valuable contributions in research.

2.

RECRUITING STUDENTS



The Need for Recruitment



Wouldn't it be wonderful if students lined to enroll in a science or mathematics research program? Suppose the principal had to hire a secretary for your mathematics or science department because of the large volume of mail received from prospective students and parents pleading to enter this specialized offering. Unfortunately, in most schools, this kind of response would not materialize nor could it be met.)

Consider a creative science or mathematics department, that has implemented the suggestions contained in this guide, and has structured a viable, realistic, research program. The unique program, measured in terms of many hours of work and enthusiasm, might very well become one of the best kept secrets in the school. The real work is about to begin. Once the facility has been built, the program needs the clientele to make it useful. The suggestions contained in this chapter have been utilized in a number of schools. For each program many of the ideas will be directly applicable. Some ideas may have to be adapted to reflect unique needs, and still others may not apply. The goal is the recruitment of as many qualified students as possible. Informing the high school community is a major step in that direction.

Student Qualifications

Who is eligible for this program? One school, in its introductory letter to the community, indicates that students selected for science/mathematics research should be at least two years above grade level on standardized mathematics and English achievement tests. In addition, this particular school requires a minimum grade of 85 per cent in overall academic achievement, with specific emphasis in mathematics and science. Finally, attendance and notations of merit or letters of recommendation are reviewed.

In some schools such criteria may not be realistic. Some teachers in schools with high academic standards may be so overwhelmed with students wanting to be part of the program that they may increase the qualifications beyond those described. Some may even utilize a "placement" examination for still further separation and selection. The overall goal is to have standards high enough to encourage a program of quality but not so demanding that the qualifications cannot be met by interested students within a community. A list of other criteria for selection follows.



Criteria for Selection

- A. Reading and mathematics scores (standardized tests) for grade level achievement.
- B. Academic achievement. Keep in mind that some feeder schools may be "easier" or more "generous" in their grading than others.
- C. Attendance record. Research requires a time commitment beyond the traditional school day, and a past history of good attendance is a desirable asset.
- D. Letters of recommendation or notations of merit.
- E. Record of previous participation in science fairs or similar activity in science.

Often a student's "scores" do not truly reflect his/her potential. Many students develop excellent projects by virtue of their enthusiasm and drive -- characteristics that usually overcome academic deficiencies. Indeed, many experienced research coordinators readily select students with high motivation above those with high achievement but low "drive".

The individual program coordinator is the best judge in determining student qualifications. Don't base guidelines on those of other communities, even those that appear to be similar to one's own. No two schools, students, or staffs are identical. Finally, don't give up. Start with a few students - others will strive to achieve and desire to be part of this special group. (In selecting students who are presently enrolled in the high school, e.g., freshmen or sophomores, use similar criteria to those used with recruitment from feeder schools.)

- CLASSROOM RULES**
- ① EVERYONE MUST REMAIN IN THEIR SEATS
 - ② NO CALLING OUT



Specific Techniques in Recruitment

Preparing a Descriptive Brochure

This very powerful tool must attract student attention and describe all the courses the program will offer. It should have an attractive, eye-catching cover, a brief statement of the program's philosophy and goals, a list of past achievements of the program, requirements for admission, a course sequence, including prerequisites and/or corequisites for advanced classes, and a complete course description for every course of study. It should be reproduced in sufficient quantity for as wide a dissemination as possible. Cost factors can be minimized by using "in-house" duplicating facilities. It might be possible to get the assistance of the Industrial Arts Department in the planning and preparation of this document.

Letters for the Science/Mathematics Research Program

LETTERS TO STUDENTS AND PARENTS

These should be attached to all applications and brochures. The letter should contain a brief description of the program, important deadlines to be considered, instructions for the preparation of the application, and the name and telephone number of a resource person who can answer parent or student concerns. In addition, a letter of acceptance should be sent to all qualified students after their applications have been processed. This letter should include a welcoming remark, date for an orientation meeting, and a tear-off portion that the parents and students should sign and return to the school.

LETTERS TO SCHOOL PERSONNEL

Letters sent to feeder schools and "in-house" personnel should include a brief description of the program and a calendar for all articulation meetings. The letter should announce at least two articulation meetings with each feeder school. First a kick-off meeting held at the high school, should involve all feeder junior high schools. Second a follow-up meeting, involving high school personnel visiting the feeder school, should be held within one week of the first meeting. Individual letters must be sent to each person who is to attend the meeting. An RSVP date should be mentioned.

Articulation with Feeder Schools

The heart of any recruitment drive is the articulation program that must be established with the feeder schools. The first series of meetings is vital because they set the tone for all future encounters.

THE FIRST MEETING

This must be informational, but its primary function is to establish a good working relationship with all personnel concerned. (This meeting might be preceded by a small collation to help set the mood.) After the spirit of cooperation has been established, every facet of the program should be detailed. A comprehensive question and answer period should follow. All feeder schools concerned should be given the names of resource people who will assist with any and all problems.

VISITING FEEDER SCHOOLS

The second meeting (or series of meetings) should entail visits to the individual feeder schools. Prior to this meeting the feeder schools, and school personnel should have had an opportunity to resolve problems that might have developed since the beginning of the recruitment drive. The eighth or ninth grade guidance counselor and/or A.P. should set up a schedule for the teacher of the program to meet with selected classes or students. At these meetings, applications will be distributed to interested students after they have been given a brief description of the program. If possible, current enrollees should accompany the teacher. Student-to-student encounters are a very effective method of stimulating interest. After meeting with the prospective candidates, one should again meet with the assistant principal or guidance counselor to review the application processing procedure.

MEETING WITH PARENTS ASSOCIATIONS

Another vital avenue of recruitment involves informing parents of prospective enrollees of the existence of the program and the many benefits to be derived by their child's participation. Plan to meet with the parents' associations of the home school as well as each feeder school. Bring students currently involved in the research program to these meetings. The students should be asked to give a five-minute speech on how the program has helped them grow. The students should also discuss their project work and any recognitions they may have obtained. Make sure to bring additional copies of applications and recruitment brochures to these meetings. A comprehensive question and answer period should be held at the conclusion of the presentation.

INVITING FEEDER SCHOOLS TO VISIT THE HIGH SCHOOL

Many of us can recall the excitement of a first visit to a university research facility, the sense of amazement as computers clicked away, flashing lights encircled the room and chemicals boiled in apparent harmony. Now, as teachers, we have the opportunity to share such



experiences with these neophyte researchers. Contact the principals of the public and parochial feeder schools in the community. Invite them to send certain classes or students to spend an hour or two at one school. Some of the activities may include:

- a) reviewing the descriptive brochure.
- b) giving a tour of your laboratories and classrooms.
- c) having students presently enrolled in the science/mathematics research program give a formal presentation.
- d) meeting the high school principal and guidance counselors.
- e) giving an opportunity to ask questions.

Planning for this activity is vital. Remember to select a block of time when facilities and staff are not overtaxed. Also, keep in mind that most students are more receptive in the morning rather than during the afternoon. Finally, rehearse the student presentations carefully, prompting students to direct their thoughts to an audience which is younger and who may lack their research skills. Always, generate a feeling of optimism, pride, and enthusiasm. It's catching.

Placement Exams

Another recruitment technique which may be used is a placement test. Such an examination could be administered during the term before students enter the program. The test can select from a large group of students those who are capable of doing individual research. Also an item analysis by the teacher may help in the design of the curriculum for the research class.

There are many materials available for constructing such a test in mathematics. The MAA exams and the New York City IML questions (see appendix) are good sources. Scholastic Aptitude Test and achievement tests are available and can be helpful.

In the sciences, achievement tests are a good place to start. Some aptitude tests contain reading comprehension questions involving scientific material. Care must be taken that the items included in the test not only include mastery of actual subject material, but also the ability to read and interpret given data.

Caution is necessary when using a formal examination to identify creativity or research ability. This type of test is frequently unreliable in measuring these qualities. Many students who have the desired ability may be overlooked. The testing situation itself, with the emotional reactions it brings into play, may hamper some students' creativity.

Most administrators of mathematics/science research classes have found that teacher recommendations and student motivation serve as the best guidelines.

Publicity

Nothing succeeds like success! The publicity associated with any significant achievement coming out of a research program is a powerful draw for others to get involved. It is important to publicize any such success as widely as possible.

A fine place to seek publicity is in local newspapers. A listing of these can be found in the yellow pages under the heading "Daily Newspapers." A short press release is often picked up by those publications.

Another place to find publicity is in professional journals. Since student achievement is also teacher achievement, publications of the New York Biology Teachers Association, the National Biology Teachers Association, the National Science Teachers Association, the Association



of Teachers of Mathematics, or the National Council of Teachers of Mathematics can often devote space to your program. For the same reason, publications of the U.F.T., the C.S.A. or the Board of Education can also provide publicity.

Any publicity the mathematics and science departments earn can be displayed and thus generate more notice. Announce accomplishments over the public address system of the school. Letters can be written to feeder schools telling them of the achievements of their youngsters, and thanking them for the excellent background that they have provided.

3.

USING THE LIBRARY



"When anyone prepares himself for discovery, he first inquires and obtains a full account of all that has been said on the subject by others."

Francis Bacon. Novum Organum. 1620.

Obtaining Information

There are many ways of obtaining information. The first and easiest process involves "asking someone." Meetings, symposia, conventions, and specific subject-area updates are held so that a group of experts can be brought together to allow one to "ask someone." This activity can provide a researcher with a "personal touch" or a "hint" that can save many hours of tedious work. The problem that many of us encounter is that we don't always have experts waiting for our questions. Thus, we must resort to the time-honored task of reading. Reading texts, reading journals, reading symposia, reading reviews, reading, reading, reading.

It is important that students become aware of the types of information sources and what they can get from each source.

Gathering and Processing Information

All researchers face similar challenges: gathering information; processing information; defining problems; designing experiments; implementing experiments; evaluating results; and reaching conclusions. Students in a science research class are going to come face to face with all of these problems. The first two process--gathering and processing information--will form the bedrock upon which a successful project is built. Students require a series of skills that will enable them to use the library, or any other informational source, efficiently. The skills teachers impart to neophyte researchers in this vital area will probably guarantee the successful completion of a project, and, more important will help them immeasurably when they begin their college careers.



Literature Research Skills

Research skills are most important in developing the research project. Encourage students to select a topic that interests them--one they desire to find out more about. Critical to the selection process is the availability of literature. Thus, the teacher must carefully scrutinize the problem and, where necessary, discourage or modify an investigation where literary research is very limited or restricted. (Exceptions are noted in the mathematics research section.)

Set Up a Time Schedule

Literature research should be an ongoing process throughout the investigation. However, we have found that some students become so involved in this preliminary phase of research that they neglect starting their project. Select a reasonable period of time for initial review of the literature. For instance, if one's goal is to have each student select a problem and design an experiment by the end of one term, you may elect to limit the initial library research to the first third of the term.

Using the Resources in the Library

Chapter one provided a partial listing of professional and public libraries available to students in the metropolitan area. Simply advising students of the availability of these facilities will not provide them with the needed direction for their use. The "trial and error" method of literature research all too often results in a great deal of wasted time. More significantly, the sense of frustration experienced by students in not being able to locate appropriate literature will hamper the development of their science/mathematics project. A more systematic approach to using the library is advisable.



Designated Areas in the Library

- a. The bookshelves or open stack area: Usually contain all the books that may be checked out.
- b. Reference section: periodicals, encyclopedias, dictionaries, abstracts, etc., are located in this section. These publications are generally not available for circulation and must be used within the library.
- c. The vertical file: Usefulness varies in accordance with skill and time of library staff. Basically, vertical files are a collection of brochures, newspaper clippings, magazine articles, and other resource materials that may be of interest in researching a particular subject. The material, organized into subject folders, provides an interesting contrast to standard texts and enlivens the research paper.

The Card Catalogue

All libraries maintain a series of small drawers containing catalog cards listing the books available in the library. Most libraries cross-reference these publications by author, title of book, and in some cases by subject.

A typical information card in this catalog will include:

- a. call number - a key to finding the book on the shelves. Dewey Decimal or Library of Congress classifications may be used.
- b. author
- c. title
- d. publisher, place of publication, and year published.
- e. book size, number of pages, illustrations.
- f. other forms of information such as the availability of a bibliography, index, glossary, etc.

Reader's Guide to Periodical Literature

Articles from over 100 publications are indexed in the Readers' Guide. Most references are listed under the author's name and at least one subject heading. Some assistance will most likely be required in deciphering the code system or abbreviations used in this guide. Bi-weekly, quarterly, and annual volumes allow the researcher to obtain the most recent research while providing a rapid means for reviewing previous material.

Newspapers

Many libraries have available copies of daily newspapers for immediate reference. Obviously storage of these papers would not be practical. Thus an "index" of subjects reported in major papers is usually the alternative selected. For instance, The New York Times Index will list subjects by date and page number and include a very brief abstract of the contents of the article. Most libraries retain microfilm or microfiche copies of back editions of the Times and other periodicals.

Abstracts

Abstract publications in nearly every subject area are published. University and professional libraries often subscribe to a variety of abstracts. For instance Biological Abstracts, Mathematical Abstracts and Education Abstracts are but a few available. Many hours of research may be saved by reviewing an abstract of an article as opposed to reading the entire manuscript. As indicated in Chapter Two, student access to the library may be restricted. Therefore, the teacher of the research class must establish liaison between the school and the professional or college library to allow students to use these facilities

Textbooks

In order to establish a good working background in a particular area, for example, "A Report on the Life Activities, Structure and Culturing of Physarum polycephalum," it will be necessary to work from textbooks. Even though the information might be one or two years old upon publication, the information students obtain from texts will provide them with a solid foundation for their future work. After students have established a background of information, they are ready to begin to formulate a problem. At this point they will have to be directed to specific research papers.

Research Papers

DIFFICULTIES INVOLVED IN THE RESEARCHING OF PAPERS

Following their first trip to the library, each student will become aware of the greatest problem he or she will face in the research project. There is a large amount of literature. This might be a good time to point out the word RE-SEARCH means to look again, and again, and again!

The more specific the informational needs of students become, the greater the problems become. Apart from volume, availability becomes a concern. It might be difficult to locate a particular paper because few libraries may carry the publications in which the paper was printed. If the paper is found, the student might be surprised to find that it is written in Japanese, French or Russian. Yes, the search for information will frustrate many of the students. The teacher should keep this in mind and provide as much help as possible.

SOURCES OF RESEARCH PAPERS

One of the most important tools to give student researchers is a knowledge of what can be found in the different sources of information. The specific area journal (e.g., Journal of Bacteriology), review journals (e.g., Microbiological Reviews), symposia (e.g., Cold Springs Harbor Symposium) and abstract journals (e.g., Biological Abstracts) are four important, different types of sources of information.

SPECIFIC SUBJECT JOURNALS

These publications give the researcher the most current articles published in a particular area. The writers report on the results of individual experiments. Included in these articles are detailed materials and methods, introductions and bibliographies. If a student is looking for a particular research procedure, the specific area journal is the best source.

REVIEW JOURNALS AND SYMPOSIA

Publications such as the Symposium of the Society for Experimental Biology, the Annual Review of Physiology, and Microbiological Reviews provide the new investigator with a historical background for a particular problem with a minimal expenditure of time and effort. These publications have been in existence for many years and they are excellent sources for bibliographies. The review journal does not provide the researcher with specific information about materials and methods, but they are valuable tools

ABSTRACT JOURNALS

Every research article is published with an abstract. An abstract is a brief summary of the nature of the research, the results and the conclusions. Using an abstract:

- . enables an investigator to determine if a certain article is of sufficient interest to warrant reading;
- . provides a quick method of keeping up with trends and current literature;
- . gives a brief summary of an article so it they may be read more intelligently with the main facts in mind.

BIOLOGICAL ABSTRACTS

One of the most powerful literature-searching tools a student can acquire is a knowledge of how to use a journal such as Biological Abstracts. The publishers of Biological Abstracts have put together a guide entitled, Guide to the Indexes for Biological Abstracts and Bioresearch Index. It is suggested that the research teacher obtain a copy of this guide to assist in the teaching of the use of Biological Abstracts and Bioresearch Index

The key to the use of Biological Abstracts is the B.A.S.I.C. (Biological Abstracts Subject in Context). This index provides the researcher with abstract numbers and an alphabetical arrangement of the key terms (search terms) for every title that is published in these journals. In addition, an author index, biosystematic index and a cross index are provided. Thus, a "well armed student" can quickly find information on the topic being researched. The worksheet on p. 41 will provide students with one method of organizing their work.

Science Research Abstract Worksheet

Broad Interest _____

Specific Interest _____

1. Use of BASIC

Step 1. Prepare a list of search terms

Step 2. Check if there are synonyms you can use in addition to the terms listed in Step 1.

Step 3. Refer to BASIC for these search terms: note reference numbers

Step 4. Eliminate reference numbers that are repeated due to synonymous terms.

Step 5. Note the subject headings under which abstract is printed. Refer to this subject heading in CROSS Index. Note reference numbers for additional material pertaining to subject under study.

2. Use CROSS Index

Step 1. Select subject headings which pertain to your field of interest.

Step 2. Compare reference numbers listed under each subject heading. Note additional identical reference numbers.

Step 3. Locate references in Biological Abstracts and Research Index

3. Use of Biosystematic Index

Step 1. Check taxonomic categories (phylum, class, order or family) for organism interest.

Step 2. Note abstract numbers

Step 3. Locate reference in Biological Abstracts and Bioresearch Index

4. Use of Author Index

Use to locate abstracts if author is known or if you are following a particular author's work or to compile a bibliography.

Student Guide for Organizing Readings for the Research Paper

Preliminary Outline

Making a preliminary outline will provide direction both in scope and sequence for your library research. Start with a series of questions to be answered. After listing the questions, develop a more complete outline from these and other questions that arise as you begin research.

Recording Your Readings

This is probably the most time-consuming chore in library research. After you have located, and skimmed through a particular item, you must store the information for retrieval when writing your paper. Many researchers find that a 3 x 5 or 4 x 6 index card is suitable for this purpose. You should include an abstract of the resource item and all bibliographic information including the page numbers pertinent to the research.

Use a separate card for each reference source, and standardize the format used on those cards for note-taking. For example, you may elect the following format:

1. title of publication, date, publisher, pages
2. author(s)
3. notes

Revising Your Outline

When you have had a chance to review the literature, you probably will decide to make changes in your preliminary outline in final preparation for writing your paper.

Organizing a Library Lesson

Science and mathematics teachers who feel that instruction in how to use library research facilities is not their forte consider asking should the school librarian to provide a series of lessons devoted to the proper use of a library.

The librarian will need some lead time to organize material for distribution and demonstration purposes. Thus, plan in advance (perhaps one or two weeks) the format for these lessons. Typical library lessons may involve:

- a.. orientation of library facilities, e.g., stacks, reference areas, etc.
- b. use of reference materials: encyclopedias, newspapers
- c. understanding abbreviations used in the Readers' Guide to Periodical Literature or the New York Times Index and various abstracts available in the library.
- d. instruction in the use of microfiche machines

Some librarians may even provide lessons on aspects of writing the research paper such as: footnoting, bibliography, etc.

Use of the Library for Mathematical Research

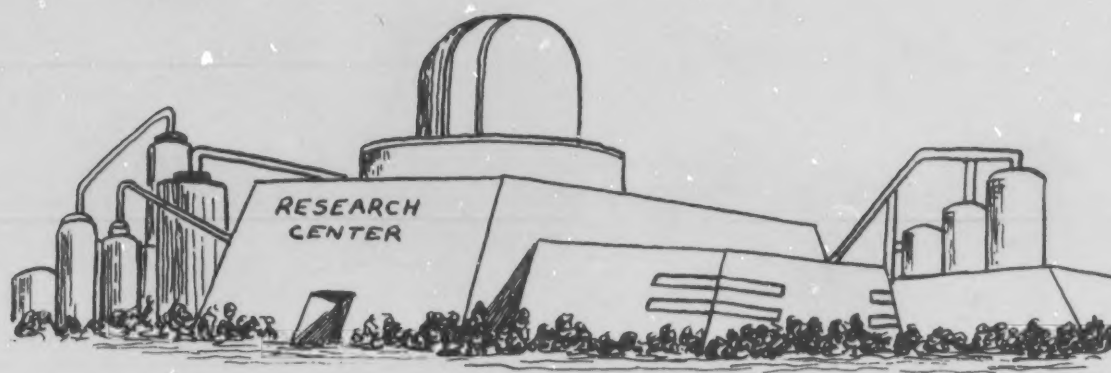
The role of library research in mathematics is somewhat different from that in science research. Textbooks and journals go out of date much more slowly--over decades rather than years. The level of recent academic research is usually too difficult for high school students. Most important, there is a stage of mathematical research when it is important NOT to be influenced by work which has already been done. This is the stage when the student has already chosen a topic and is working on it on his or her own. At this stage, the student's chief task is to find an original way of understanding the problem.

Nonetheless, the guidelines about the use of the library can be helpful in mathematics research. A student who is first seeking a topic can be sent to texts or journals for something which catches his or her eye. A student who has done some individual investigation and needs more background can also find this in the library. Students who find themselves stuck may be able to get some idea of how to proceed through a similar discussion from a printed reference.

In mathematics, as opposed to the sciences, students can build from their current state of knowledge, without referring to outside sources. Hence these sources play a much more tangential role in mathematics. Some exceptions to this rule are research in computer science, and in the history of mathematics.

Teacher's Notes





4.

USING OUTSIDE AGENCIES

PART I — SCIENCE

Introduction

The primary responsibility of the science/mathematics research program is to provide students with the fundamental techniques needed to develop and implement their research projects.

The instructor who is successful in this endeavor will discover that the level of academic preparation required for the completion of the research paper rapidly surpasses the references available in the school library.

In addition, the need for more sophisticated laboratory techniques will become apparent as students grapple with gaining a greater degree of accuracy in their experiments.

This chapter will consider some of the problems related to advanced research and offer suggestions on how these may be resolved.

Library Resources

It is almost impossible for any library to possess all of the references required for adequately researching a given topic. A number of public, private, university and specialized libraries were listed in Chapter Two.

The instructor should contact the administrators of these libraries to determine the specific regulations governing the use of the facility. A letter introducing the student, and acknowledging appreciation to the library officials is appropriate protocol and should be followed.

Medical Institutions

The use of a medical facility permits a unique opportunity for both recipient and donor. Most hospitals welcome conscientious, sincere, enthusiastic volunteers. Many will permit these volunteers to assist in the hospital laboratories and where possible become involved in research being conducted by their staff. This opportunity affords students a chance to learn contemporary laboratory skills. As with the use of private libraries, the instructor should make the initial inquiry. The instructor should indicate to the administrators of these facilities the specific needs of his or her students, and should emphasize the mutual benefit that would result from the collaborative effort.

Special Concerns

1. Is there a minimum amount of volunteer time required by the institution?
2. Can the teacher obtain early release from school so that the student may start the internship at a reasonable hour? Will this allow the student to return home early enough to complete other school requirements?
3. What kind of research is being conducted at the institution, and what role will the student be playing?
4. Will the student be exposed to potentially dangerous situations?
5. Has the teacher obtained permission from parents and school officials for the use of these agencies?

Medical Institutions in the Metropolitan Area (Partial Listing)

Bronx Children's Pyschiatric Center
100 Waters Place, Bronx, N.Y. 10461
430-7248

Brookdale Hospital Medical Center
Brooklyn, N.Y. 11212
240-5615

Cabrini Medical Center
227 East 19th Street, New York, N.Y. 10003
725-6667

Coler Memorial Hospital
Roosevelt Island, N.Y. 10044
688-9400

Creedmoor Psychiatric Center
80-45 Winchester Blvd, Queens, N.Y. 11427
464-7500

Lenox Hill Hospital
100 East 77th Street, New York, N.Y. 10023
794-4200

Montefiore Hospital
111 East 210 Street, Bronx, N.Y. 10467
920-4191

Mount Sinai Medical Center
1 Gustave L. Levy Place, New York, N.Y. 10029
650-6288

New York Infirmary
170 William Street, New York, N.Y. 10038
233-5300

Queens Hospital Center
82-68 164th Street, Jamaica, N.Y. 11432
990-2669

Rockefeller University Hospital
1230 York Avenue, New York, N.Y. 10021
570-8474

St. Vincent's Hospital
153 West 11th Street, New York, N.Y. 10011
790-8687

V.A Medical Center
800 Poly Place, Brooklyn, N.Y. 11209
836-6600

Others, check your local phone directory for medical institutions that are within the vicinity of your school community. Travel time is of prime importance and will affect the enthusiasm and motivation of your students.

Universities and Colleges

City College of New York

York College

Pace University

New York University

Columbia University

Queens College

Brooklyn College

Wagner College

St. John's University

Long Island University

Hunter College

Special Notes to Teachers

In addition, a host of community and specialized two-year colleges are available in the metropolitan area. Many of these institutions have programs in concert with the Board of Education. These programs can provide the student with college credit from the host institution. Involving students with colleges during their high school careers is an excellent transition for conditioning these students to the rigors of academia on a higher plane.

Other Outside Agencies

Museums:

- . American Museum of Natural History
873-1300
- . Metropolitan Museum of Art
879-5500
- . Staten Island Museum
727-1135

New York Aquarium
266-8624

Bronx Zoo
367-1010

Wave Hill Environmental Studies
549-2055

Alley Pond Environmental Council
229-4000

7.

SELECTING THE PROBLEM



PART I — SCIENCE

Introduction

The science research program that is implemented in a high school must be geared toward preparing students to function independently. The teacher must give students a set of skills that will enable them to design, perform, evaluate and update a scientific investigation--a problem. Possibly even more important than the hands-on skills, is the teaching of problem-solving thinking. Once a student's thinking is set on the correct course, the teacher's job is to help guide the student to a problem to be solved in the atmosphere of the high school laboratory. Before the problem-solving process is taught, it is very important that students understand that the projects or problems they will work on need not be of a Nobel Prize caliber. Indeed, most projects will involve a simple, straightforward design.

At this point, it is important to borrow a thought from the mathematician. Frequently, mathematicians will solve difficult problems by simplifying them into several smaller, less involved problems. Of course, the big problem is simplifying the work into smaller, easier problems.

Teaching Problem Solving

Although all students have been exposed to some instruction in problem solving techniques, the science research teacher can't risk the possibility of some of the students not being familiar with this important skill. Each student must be imbued with the thought that the conclusions or concepts he or she will study or produce will come directly from data and conceptualizations. The students must be taught to become careful observers, measurers, and designers. All of the laboratory skills taught must stress these concepts. Also, each student must be taught that the evaluations and conclusions made not only come directly from the data, but should not go beyond the data generated from the investigation.

To get students to think about problem solving, it is important to supplement the basic laboratory skills with problem-solving situations. The BSCS Biology Teachers' Handbook has a section entitled, "Invitations to Enquiry." This section is made up of 44 sample problems that will help the teacher direct student thinking towards the problem-solving process.

For example, students will be taught to make careful laboratory measurements. Either before or during the first series of laboratory exercises, the students could be given invitations which deal with measurement -- systematic and random error.

Science Research Exercise

Over a period of a week, four students made five measurements each of a metal bar which was kept in the laboratory. They were given the impression that they were measuring a different bar each time. The record of their measurements (in millimeters) is as follows:

Measurement	Student #1	Student #2	Student #3	Student #4
1.	500.0	500.0	499.8	500.0
2.	499.9	500.0	499.9	500.1
3.	500.0	500.0	500.1	500.2
4.	500.1	500.1	500.2	500.3
5.	500.2	500.0	500.2	500.3

1. Notice the difference between the measurements reported by student 2 and those reported by 1, 3, 4. How would you describe the difference?
2. Now compare the measurements reported by student 4 with the other reports. What overall difference is there? How would you explain the difference?
HINT: Think of the measurement you would get if you read the right end of the measuring stick while standing at its left end, with the stick on top of the bar measured. Then think of the same measurement made as you stood at the right end of the measuring stick.
3. Suppose a later experiment required an estimate of the length of the bar, to be used in many arithmetic calculations. In that case, what estimate would you choose as being "good" enough and also convenient? If a future experiment required an estimate that was statistically valid, what number would you choose? How would you get the number?
4. What could you do to make the best estimate even more reliable?
5. There are two ways to secure additional measurements. One way would be to have the same student do the job. Another would be to call on additional students to contribute. What kind of error, systematic or random, would be reduced more by the second method than by the first?
6. Now inspect the results column by column, from the top down. What trend is noticeable? What besides the new sort of systematic error might explain the trend? HINT: The metal bar was measured over a period of one week.
7. Suppose that the trend just discussed had been overlooked or treated as an experimental error. Further, suppose that the measurements were used to support a certain theory according to which the rod ought to be nearer to 500.1 mm. long rather than to 500.0 mm. Unless this experiment were repeated by others at different times and places, what might happen to the field of study that defended this theory?
8. In view of your answers to 6 and 7, explain what is meant by saying that science is a social enterprise.

This simple exercise helps students understand the relationship between data and struggle for accuracy. When the students are taught the correct method of massing material on a pan balance or analytical balance, the points stressed by this exercise will be driven home. The creative teacher can learn to gear these invitations to any science area. The experience of sifting through a series of these problem-solving situations will assist immeasurably when the students begin the process of choosing a problem for research.

Choosing a Problem

One of the most important steps to be taken by a student in a science research program is choosing a problem. This activity will set the stage for the students' work for the remainder of the first year and, if elected, all of the work in the second year of the program. It is important to note that the process of choosing a problem is a very powerful learning experience. Even if the problem never gets off the ground, the process the student experiences has provided invaluable learning. The problem must be redesigned until a workable situation is achieved.

One of the reasons New York City is a national leader in the area of high school student research project achievement is the relative ease with which information can be obtained in this city. Thus, the ability to do the background research in order to select a problem does not pose great difficulties.

There are limiting factors that must be considered regardless of the science in question. Degree of difficulty, time, facilities, student ability, expense, and special conditions are major parameters for the selection of a problem.

Degree of Difficulty

A research student may approach the instructor with an idea of studying the effects of DMSO on the formation of gobbets in the cytoplasm of Ameba proteus. The instructor must point out that gobbets can only be observed using the high-voltage electron microscope and special staining techniques. Thus the project, although possible, is a bit too ambitious for a traditional high school laboratory. The teacher might suggest that the student study the effects of DMSO on the survival rate of Ameba proteus exposed to freezing and thawing. This alternative, which sounds just as impressive, is well within the limits of a high school laboratory.

Time

Since most science research programs will allow six to eight months for actual laboratory research, time is a very important factor. If a student wished to study the effects of ultraviolet light on the growth of antonium galitsisium crystals in a supersaturated solution, it would be the job of the instructor to point out that it takes 7.5 months to grow one series of antonium crystals. If the student still wishes to do this project, a suitable substitute for antonium (copper sulfate) must be made.

Experimental design, gathering materials, running the experiment, and the initial literature review are time-consuming factors that must be considered when choosing a problem.

Facilities

The limiting factor of the gobbet experiment cited earlier was the lack of equipment. When selecting a problem, the student should keep in mind the limits of the laboratory in which the project work is going to be done. If the project is to be researched in the high school laboratory, it must be simple in terms of equipment demands. Although the use of student constructed apparatus can help, the basic premise of workability must be kept in mind. If a student can work at a college or private research facility, the problem of equipment may be overcome more readily.

Student Ability

This is a very subjective area. The instructor must be able to help the student select a problem that is within the scope of the student's intellectual and laboratory skills. The instructor must remember that the students are guided towards goals that will enable them to expand the limits of their intellect, not work below these limits. Another important factor to be considered is the range of knowledge of the instructor. This problem can be overcome by establishing a liaison with instructors at other local high schools, colleges and universities. The use of other members of the school's faculty should not be overlooked. English teachers, for example, may be able to help students edit science research papers.

Expenses

Although the school facilities can provide material for many "in-house" projects, special funding (See Chapter Two) may still be necessary. It is unreasonable to expect the student to provide between 50 to 150 dollars over the course of two years to help finance a research project?

In addition, slight expense might be incurred in setting up a mini laboratory in the student's home. Remember, Euglena, Paramecia, Physarum and Dictyostelium do not work a 40-hour week. On-going observations might make the "at home" lab necessary.

Special Conditions

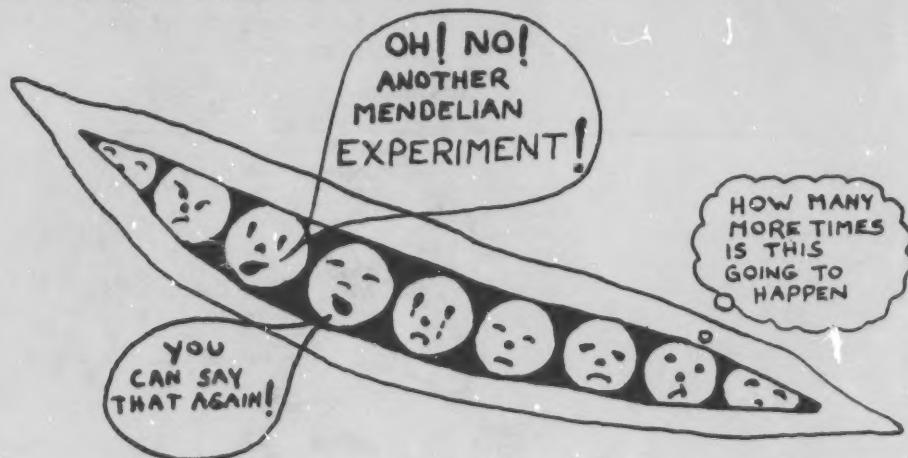
Student ability, interest, family background and special facilities available to an individual will all play a role in determining the degree of difficulty of the project the student will research. In the biological sciences, the limited use of vertebrates must be considered when students select an organism for a research project. The facilities and expense for obtaining certain organisms must be evaluated before the instructor allows a student to begin working in a particular area of research.

Classification of Problem Types

A cursory review of problem titles listed in science fair booklets will quickly reveal the enormous variety of projects that are possible. Quite literally, the subjects vary from astronomy to zoology. Problem types may run the gamut from collections to investigative experimentation. Regardless of the topic or type, the student, in order to be successful, must find the project interesting, stimulating and worthwhile. However, it will be of value in motivating the students to make them aware of the many varieties of problems from which they may choose.

Repeating an Experiment Performed by a Mathematician or Scientist

A student may elect to research the work of Gregor Mendel and to duplicate a series of experiments conducted by this scientist. The results may then be compared with present understandings in this area.



Another possibility may be to build an apparatus. For example, a photometer, although not original, is a worthwhile project.

Physical science enthusiasts may wish to determine the accuracy of Archimedes' or Bernoulli's principles.

Collecting Materials

A mere collection of things is not a science project. However, if the collection provides insight into a particular scientific phenomenon or explains an occurrence, then the value becomes much more meaningful and productive. For example:

- . A collection of flora around the school community could shed light on the effects of air and water pollution.
- . Growing and collecting "crystals" under a variety of conditions become the basis for understanding relationships existing between atoms.
- . Collections of "rock types" may reveal the geology of a region and portend signs for the future.

The Design and Development of Scientific Apparatus

Students who are mechanically inclined may find this area to be of particular interest. The teacher should insist on "functional" apparatus as opposed to "model building." For example:

- . Constructing various types of micro-dissection items will be a source of satisfaction to the designer as well as to researchers who may find the apparatus valuable in their work;
- . A "working wind tunnel" can lead to an understanding of aerodynamics and to a variety of projects that will make use of the apparatus;



- . Redesigning of "weather" measuring devices (e.g., an anemometer) can result in data almost immediately upon completion. Accuracy of these student-designed instruments can be compared to conventionally available devices.

Testing Advertising Claims for Certain Products

Students are continually inundated with claims of product efficiency. They now have an opportunity to test the accuracy of those advertisements:

- . Does a famous brand of mouthwash really destroy bacteria found in the mouth?
- . Is there any difference between different brands of "pool water chlorine"?
- . How do different brands of fertilizers compare in effectiveness?
- . Are there differences in the relative cleaning strengths of various detergents?
- . Can picture quality of different brands of "film" be compared?

Conducting a Survey

The news media, marketing analysts, and a host of other professions often quote "survey" findings to support their conclusions. Psychologists and sociologists are highly dependent upon surveys and spend countless hours designing an appropriate survey tool. For example:

- . A survey of the colleges attended by graduates of your high school over a period of time may reveal certain sociological trends in the community.
- . The effect of viewing television commercials on the selection of products purchased in a department store provides insight into the "buying" preferences of the public.

As you review the various problem "types," you may discover that a truly "investigative" research problem utilizes many skills commensurate with the categories suggested. Classifying a project as "survey" or "collection" is not in keeping with the development or implementation of the problem statement. The nature of the problem and the selection of a project organism or phenomena will determine, to a large extent, the type of project format that will be used.

There is a great deal of overlapping among problem types from which students can get ideas for their projects.

How to State the Problem

In Chapter Five, "How to Write a Research Paper," we indicated that a correctly worded "problem statement" should permit the reader to understand the gist of the project without reading the entire paper. Guidelines for writing the problem statement include:

- . a simple, clear, concise statement written in good English;
- . a statement that explains exactly what the experimenter or researcher is going to find out.

Compare the following poorly written problem statements with the properly worded statements:

<u>Incorrect Statement</u>	<u>Corrected Stated Problem</u>
1. Nutrients and fruitflies	1. What is the effect of vitamin C on the growth of <u>Drosophila melanogaster</u> ?
2. Crystals and electricity	2. How does an electromagnetic field affect the growth of salt crystals?
3. Studying certain physiological conditions of the paramecium	3. How do changes in pH affect the reproduction and growth of <u>Paramecium bursaria</u> ?

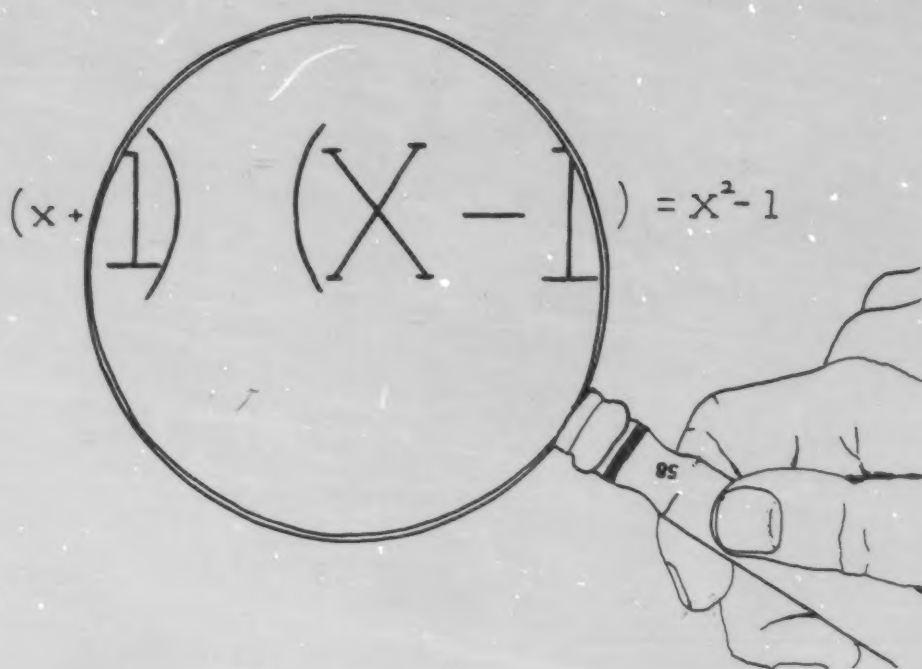
Repetition may serve to highlight the importance of a proper problem statement. Avoid ambiguity by including sufficient information in the problem statement to:

- . clearly describe the specific organism or condition to be investigated;
- . define the parameters of the variable in the experiment;
- . state the relationship between the variable and condition or organism under investigation.

The final test of a problem statement is whether or not it conveys to a reader what the experiment is about. Advise each researcher to have a fellow student read the problem statements, and restate it. If the way the student reader expresses the problem does not agree with the writer's plan for the experiment, the problem statement must be rewritten and the process tried again until it is clear to a reader.

Samples of Problem Statements

1. The variation in electrical resistance of the human skin during physical activity.
2. Antibacterial substances from Zea mays (corn) seeds.
3. The influence of NaCl concentration on the morphology of Artemia gracilis (brine shrimp).
4. The action of thyroid extract on the pigmentation of Rana pipiens (frog).
5. Relative toxicity of detergents on the growth and development of trout perch (order percopsiformes).
6. The effects of steroid hormones on the growth of Bacillus subtilis.
7. A model recycling plant for solid wastes.
8. Use of aluminum in hydrofoil design.
9. Weathering effects on aluminum.
10. The engineering and design of a suspension bridge.
11. Competitive inhibition of Bacillus subtilis and Serratia marcescens.
12. The effects of changing temperatures on the conductivity of selected salt solutions.
13. The effects of magnetic fields on colony formation in E. Coli.
14. The relationship of rock strata to the occurrence of index fossils.
15. Comparing light intensity with the rate of photosynthesis (bean plants).
16. Measuring intensity of light in a vacuum.
17. Retarding spoilage in apples through the use of auxins.
18. Comparing the absorptive characteristics of filters from four different brands of cigarettes.
19. The effect of nitrogen deprivation in the nutrition of insectivorous plants.
20. Insulin-induced micromelia in starfish embryos.



7.

SELECTING THE **P**ROBLEM

PART II — MATHEMATICS

(TEACHING **PROBLEM—**S**OLVING **S**KILLS)**

Guest Speakers

Inviting guest speakers to demonstrate or lecture is an excellent means of maintaining the interest of students. The students will obtain an appreciation of how a scientist develops an area of research. The opportunity to discuss scientific findings with a professional scientist is of inestimable value in motivating the students to pursue their projects with renewed enthusiasm.

GUIDELINES

- a. Discuss the scope of the lecture with the speakers:
 1. time allowed
 2. nature of audience
 3. topics to be discussed.
- b. Present this outline to the principal in order to obtain formal permission for inviting the speaker to the school.
- c. Prepare students prior to the visit so that they will derive maximum benefit from the lecture. For instance, tell them the topic to be discussed, and ask them to prepare questions they may wish to ask.
- d. Plan for a follow-up lesson to discuss the speaker's presentation.

SPECIAL NOTES

Many agencies have an ulterior motive that becomes part of their presentation. For instance, a researcher from a college may request a period of time to discuss the course offerings at that college and thus encourage students to enroll. This aspect of their presentations is not necessarily negative unless it becomes the major point of reference in the lecture. Indeed, career guidance is an ongoing aspect of instruction that should be integrated within the research program.

Representatives from colleges, universities and industry are excellent resources for career information. Their experiences will assist your students in planning for their future, and serve as additional motivation in encouraging the students to continue their research.

Summer Programs

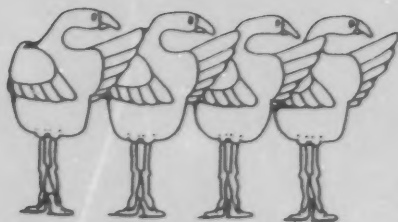
National Science Foundation and various summer science institutes are excellent opportunities for students to learn first hand the demands of science research.

The skills acquired, concepts developed, and experiences attained cannot be duplicated in the classroom. The National Science Foundation publishes a listing of Summer Science training programs each spring. Unfortunately, many of these programs are no longer funded by the Federal Government and now require a substantial investment on the part of the student.

Some programs, particularly those listed in the guide published by the Junior Academy of Sciences, enlist volunteers and do not charge a fee.

4.

USING OUTSIDE AGENCIES



PART II — MATHEMATICS

Since mathematics research does not require much equipment, the chief resources that outside agencies have to offer are guest speakers, consultants, and libraries.

Guest Speakers

Inviting guest speakers to the school creates excitement in the research class in many different ways. The students get to see firsthand how a working mathematician thinks about a problem and to hear about his/her own current research. If the speaker's personality is outgoing, his or her enthusiasm will affect the students. Students often come to think of the guest as a role model for their own professional lives.

The New York City Chapter of the Mathematics Association of America maintains a speakers' bureau. A list of speakers is published, together with topics they can present. Many of the speakers are quite experienced at reaching a high school audience. Arrangements may also be made by personal contact between the advisor and a university. Frequently, the office of admissions is willing to act as a go-between in arranging for speakers.

Consultations

A call to a university from the high school assistant principal or research advisor can sometimes make it possible for students to consult experts in their fields of interest. Speaking to mathematicians about their ideas can be inspirational as well as educational.

Such consultations can be particularly important in a paper combining mathematical methods with investigations in the social sciences. The construction of statistical models frequently calls for experience as well as inspiration.

Libraries

Many college and university libraries have excellent mathematics collections. Most of these facilities will make it possible for students to use the books and other reference material although they generally do not allow borrowing.

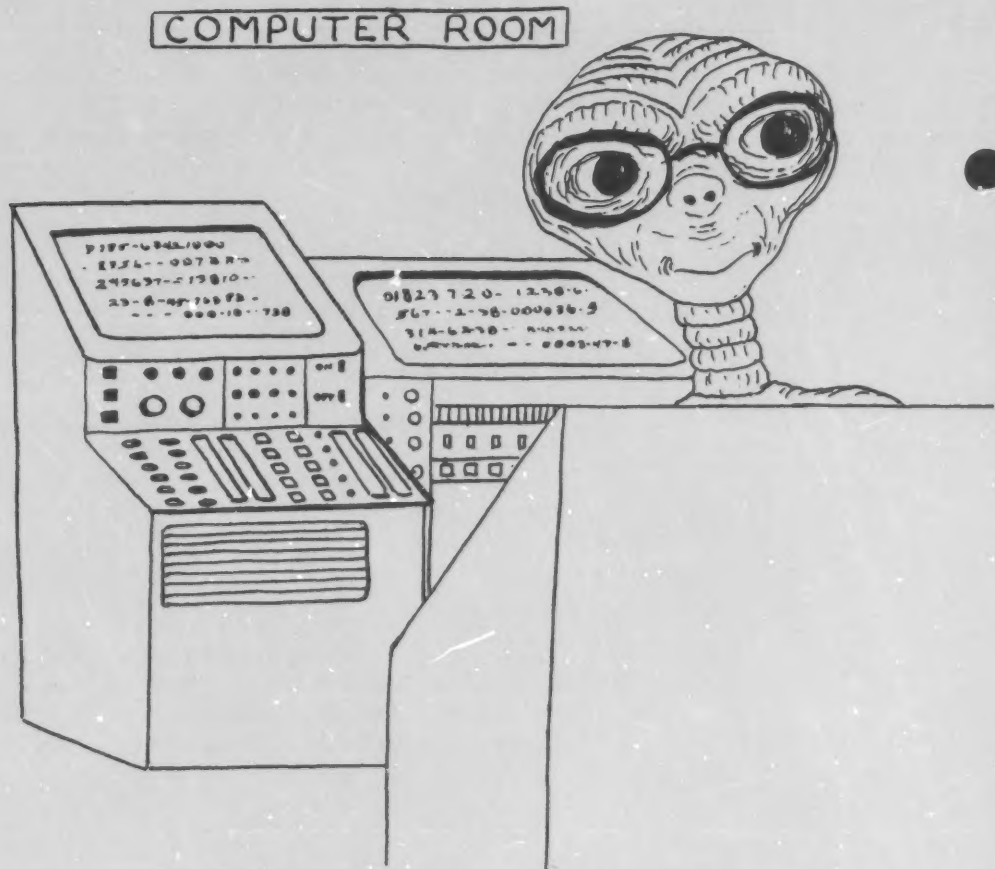
Computer Facilities

Often a student's work will require more sophisticated computing power than is available in the high school. Should the need arise, a contact with a college or university can sometimes get the students onto a computer

with greater capacity. However, it is not always possible for students to use the computers at will because university computer facilities are heavily used and there are periods of peak demand.

Summer Institutes

Summer institutes for high school students are run by various colleges and universities. Listings by the National Science Foundation and by the Junior Academy of Science are available each spring. A summer spent at one of these programs can be a very influential experience for students. Apart from the intensive training they receive during the summer, students find many friends who have the same interests and abilities. Friendships grow into collaborations, and the whole scientific community is enriched by these contacts.



5.

WRITING THE RESEARCH PAPER



PART I — SCIENCE

Planning for the Research Paper

One of the most important skills that students in a science research program must acquire is the ability to write a scientific paper. Indeed, if the only skill students carry away from the science research course is the ability to write a scientific paper, they have been given one of the most powerful tools in the arsenal of skills needed for success in college or a career in science. When students who have passed through a science research program return for a visit, they will probably thank their instructor, not for the award which they may or may not have won, not for the project work which they may or may not have remembered, but for the blood, sweat, and tears that both gave to the teaching and learning of how to write a scientific paper.



The format that is set down in a later part of this chapter must be etched into our neophyte researchers' minds. It must be pointed out that the process of writing a scientific paper evolves over a period of time. The students must be made to understand that a scientific paper is supported by two pillars. One is the laboratory experimentation which may supply new data for our body of knowledge. The other is the library research that produces information or data from the myriad of sources so painstakingly reviewed and digested.

The process of writing a scientific paper begins after the students have been taught to use the library. The first comprehensive paper the students produce may be on a single topic report, e.g., a report on a single organism. In biology, each student selects an organism that will be cultured, maintained, and probably used in a research project at some future date. The paper is written in the style and format of a "typical" scientific paper. The paper includes a title, abstract, table of contents, introduction, materials and methods, results, discussion, conclusion, literature cited and bibliography sections.

Even though this is a library research paper, by the time it is due, the students will have cultured the organism in the lab so they have information for the results and discussion sections.

While library research has begun on an organism paper, the students may do a group project involving the effects of a particular variable--for example, carbohydrate source, temperature, or pH on the fermentation rate of Saccharomyces cerevisiae. They might prepare a brief scientific paper on this project. The function of this paper is to give the students experience in collecting laboratory data and then integrating this data with the library data each must acquire. Almost all students rewrite this first effort because they have yet to acquire the scientific writing style or the organizational ability to write the paper correctly the first time.



The students then search the literature for a project proposal. This paper may involve the exposure of an organism to a controlled condition. The standard format may be used, but there need not be sections dealing with results, discussion or conclusion. The function of this paper is to get the students to search the literature so that they become "experts" in the "controlled condition" being studied and the methods and materials to be used.

The research teacher, by this time, has become an advisor, supervising 20-30 different research projects. The teacher must work closely with the student to make sure the paper being written will pose a problem that can be solved in a high school laboratory. To insure this, the paper may have to be submitted as many as three times.

By the time the first year of science research has been completed, the students have submitted at least six to eight papers. By the time June rolls around, the students have learned to write a scientific paper.

Before and during the writing of the scientific paper, the teacher of the science research class can give students a number of suggestions that will assist them in acquiring the style to be used.

Suggestions to Students

1. Read a number of papers published in journals such as the Journal of Bacteriology, Microbiological Reviews, or Applied and Environmental Microbiology.
2. Read the "Instructions to Authors," published by the Journal of Bacteriology (see page following). A thorough discussion of these instructions, and the scientific style of writing before pens are set to paper, will help immeasurably.
3. Put aside the first draft for two days before you make an attempt at revision. It is less probable that you will "think" the same error again and will probably see the work as a reader rather than as a writer if some time has elapsed.
4. Read the first draft thoroughly. Care must be taken to look for gaps in the train of thought that require revision. Ideas must be developed clearly and adequately for readers who may be unfamiliar with the subject being discussed. The logical order of ideas--simple to complex, known to unknown--must be checked to insure that the material is presented in clear-cut stages that the reader can follow.
5. Have another person read the revised draft--preferably a researcher or English teacher.

After this preliminary preparation you are ready to begin the development of your papers.

Although the text concerns itself with examples such as the *Journal of Bacteriology*, etc., the same procedure can be used in the *Journal of Physical Chemistry*, *Journal of Chemical Education*, etc.

Instructions to Authors

Form of manuscript: All parts of the manuscript should be typed double-space or, preferably, triple-space. Most manuscripts can and should be divided into the following sections: Abstract, Introduction, Materials and Methods, Results, Discussion, Acknowledgements, and Literature Cited.

Title: A single statement of the subject of a paper is preferred to a main title-subtitle arrangement. A short version of the title (no more than 46 characters and spaces) should be supplied for use as a running head.

Abstract: An Abstract appears at the beginning of each paper in the Journal. The Abstract should not exceed 200 words.

Literature Cited: In the text, references are cited by number. The Literature Cited section should be typed in alphabetical order, by first author, and numbered. Each reference should include the title of the article and inclusive pagination. Names of journals are abbreviated according to Bibliographic Guide for Editors & Authors (American Chemical Society, 1974). Citations of abstracts, theses, "unpublished data," "personal communication," and "in press" will not be accepted in the Literature Cited.

Tables: Each table should be typed on a separate page. The data should be arranged so that columns of like material read down, not across. Explanatory footnotes are permitted, but detailed descriptions of the experiments are not. The materials and methods used to gain the data should properly remain in the section of that name.

Figures: A complete set of figures, preferably glossy photographs, should accompany each of the two copies of the manuscript. Graphs (submit as photographs) should be finished drawings not needing further artwork or type-setting. Absolutely no part of a graph should be typewritten (except the legend, which should be typed on a separate page). Most graphs will be reduced to one-column width, and all elements in the drawing should be prepared to withstand the reduction. The legend of the figure should provide enough information so that the figure is understandable without reference to the text. Experimental details from Materials and Methods should not be repeated in figure legends. Figure ordinate and abscissa scales, and table column headings, should avoid ambiguous use of numbers with exponents (see p. 140, CBE Style Manual).

Nomenclature of microorganisms: In general, the nomenclature presented in Bergey's Manual of Determinative Bacteriology (8th ed., 1974) is used. If an author challenges this nomenclature, his own judgement will be followed, but the name in Bergey's Manual should follow in parentheses the first time the name is used in the text and in the Abstract. Papers which include extensive taxonomic material (e.g., description of new taxa) will not be published in this journal. The proper place for publication of taxonomic material is the International Journal of Systematic Bacteriology (IJSB), which is published by the ASM for the International Association of Microbiological Societies. If the main thrust of such a paper is not taxonomy, the paper should be divided, the taxonomy portion being submitted to IJSB and the other portion to this journal.

Notes: The accepted form for Notes is somewhat different from the foregoing. Contributors should consult a recent issue of the Journal for style. Notes should not exceed 500 words.

Reprinted with permission of the *Journal of Bacteriology*.

Developing the Research Paper

The research report is a method of communicating to people the data obtained in the experiment and the conclusions suggested by the results. The validity of a scientific experiment is based on repeatability of the procedure and confirmation of results. Thus, the paper communicates the format to be followed in conducting the experiment and the logic that structured the procedure.

As a method of communication, the paper should be written in a clear, concise manner. Flowery language is of limited usefulness in the research paper. A standardized format consistent with most research papers includes the following:

- A. title (problem statement)
- B. introduction (background readings)
- C. hypothesis
- D. materials and methods (experimental design)
- E. results (observations)
- F. discussion
- G. conclusions
- H. literature cited
- I. references
- J. appendix (optional)

It should be noted that scientific papers do not use a table of contents, and that each section of the paper follows immediately after the preceding section. In other words, do not start a new page for each section.

A. Title (Problem Statement)

The title or problem statement tells the reader precisely what is being done in the experiment. Indeed the "test" of a good title is whether or not a reader can grasp what an experiment is about without reading the paper itself. Selecting and "wording" a problem statement is a vital skill which must be acquired. How to state a problem will be further elaborated in Chapter 8. The title should include:

- a. the specific organism or condition to be investigated;
- b. the variable to be measured;
- c. the parameters of the organism or condition to be measured.

"The effects of ultraviolet light on the reproductive capacity of Paramecium caudatum" is an example of a problem statement that satisfies these requirements.

B. Introduction (Background Readings)

In this section the author discusses why the research is being conducted. It is in other words, the purpose for the investigation. Literature research is carefully summarized and annotated (referenced and placed in the literature cited section). Reference to previous research lays the foundation for the statement of the hypothesis and the formulation of the experimental design

C. Hypothesis

"...an assumption made in order to test its logical or empirical consequences."

Merriam-Webster Dictionary

Some researchers prefer including the hypothesis within their introduction, while others expound on its importance by devoting a separate section to the statement. In either case, the hypothesis logically follows the literature research and provides a framework for the experimental design. The results will either support, modify, or negate the stated hypothesis.

D. Methods and Materials (Experimental Design)

The scientific paper is written in narrative and in the past tense. This section, particularly, indicates what the researcher has done, and should not read like a class laboratory manual. The premise for this section is to provide sufficiently detailed data on what was done, how it was done, and, often, when it was done. Charts,

photographs, and diagrams are all helpful in transmitting this information. The rule in determining successful writing of this section is that the reader will be able to duplicate the experiment precisely as it was originally conducted. Most research papers do not list the materials used, but incorporate them within the narrative. One example might be:

"Three culture plates were inoculated with four drops of Paramecium caudatum."

As opposed to the following:

For this experiment you will need:

- 3 culture dishes
- 1 eye dropper
- 1 stock culture of paramecium

E. Results (Observations)

The data obtained in the experiment are presented in this section with total objectivity. (Conclusions and discussion of results are reserved for another section of the paper.) Graphs, tables, and photographs are extremely useful. However, the visuals must be properly annotated, e.g., Figure 1, Table 1, etc., and must be accompanied by appropriate narrative. For example, "The results obtained after three hours at 70°C are shown in Figure 1." Then the results shown in Figure 1 are summarized; "The number of organisms increased 25%." Consistency in writing style has been fairly well standardized. Tables are referred to as "tables." Graphs, pictures, drawings, maps, etc., are referred to as "figures." Also tables and figures are numbered independently of each other, and must be included in the narrative. A more detailed description of data collection and recording will appear in Chapter Ten.

F. Discussion

Prior to stating the conclusion, the researcher discusses what the results mean. An explanation is provided as to why certain things occurred, or why they did not. Conclusions are made based on the data, and explanations, are provided for these conclusions. The researcher compares the results with those previously found by other researchers and provides insight for future research.

G. Conclusions

The researcher restates the conclusions discussed in the previous section but without any reasons as to why these conclusions were reached.

Some readers, desiring not to read the entire paper, may elect to read the concluding section, which in effect is a capsule version of the results and discussion sections.

H. Literature Cited

Unlike a bibliographic reference section, the listing in this section, arranged alphabetically by author, cites only that literature which has been specifically referred to in the text. The details of punctuation are fairly complex, but are available in most high school usage texts. The school librarian may assist in providing guidelines for citing the literature properly. An excellent publication for writers is:

Tuabian, Kate L. "Manual for the Writers of Term Papers, Theses, and Dissertations." Third Edition. Chicago Illinois: University of Chicago Press, 1967.

I. References

When a researcher mentions any information that is not something which he or she has obtained through direct observations or experiments, it must be cited as a reference.

There are many styles that are possible, including the use of footnotes. However, we have found that most scientific papers do not use footnotes, but cite the reference directly in the text.

For instance: Most scientists accept the hypothesis that man first appeared on this planet nearly two million years ago (Goodman and Reine, 1982). That tells the reader that Goodman and Reine are the originators of that statement. The reader may elect to obtain further information on the topic by turning to the literature cited section where the authors and actual publication will be listed.

J. Appendix (Optional)

This optional section may include photographs, charts, diagrams, copies of questionnaires, etc., that were referred to in the paper. Some writers prefer this separate section as opposed to incorporating the material within the narrative.

Additional References for Teachers

1. Council of Biological Editors; Committee on Form and Style Washington, D.C.: American Institute of Biological Sciences, 1972.
2. Future Scientists of America Sponsor's Guidebook Washington, D.C.: National Science Teachers Association, 1971.
3. Guidry, Nelson P. and Kenneth B. Frye. Graphic Communication in Science. Washington, D.C.: N.S.T.A., 1968.
4. Trelease, S.F. How to Write Scientific and Technical Papers. Baltimore: Wilkins, 1958.

Abstracts

Most scientific journals require an abstract to precede the actual paper. In many cases the abstract is no longer than 200 words and concisely summarizes the scientific paper.

Strange anomaly:
The flame of intuition.
Frozen in rigor.

Katherine O'Brien

"Three Haiku: What is Mathematics?", The American
Mathematics Monthly (Mathematics Association of America),
Vol. 88, 1981.)

5.

WRITING THE RESEARCH PAPER



PART II — MATHEMATICS

Introduction

Mathematics can be thought of in many ways. Sometimes it is an art, sometimes a science, and sometimes a language. In many ways this last is the most elusive side of mathematics. Students will rapidly find this out when they meet the challenge of expressing their ideas in mathematical form.

This struggle must be begun very early. Even before students are able to think through a problem on their own, they should be asked to write up results that have been arrived at in group discussion. Their first attempts will be very clumsy. Students will not know quite what is expected of them and will not be able to recognize when the task is done.

One possible way of showing them what is required in writing mathematics is to show them a model. The teacher can take an article or textbook which discusses some result with which the students are acquainted. Then he or she may guide them through the process of reading the formal language, showing them how the insights with which they are familiar are expressed formally.

After this, exercises can be assigned for solutions at home, and formal exposition of the solution can be required. Students should write in a formal mathematical style once or twice a week. This part of the course puts a heavy burden on the teacher. The students will be generating tons of paper which must be read through. One useful technique which can help reduce the teacher's load is to have students read each other's work. They exchange papers, and each must be able to understand the other's writing without asking questions. This process can help both the reader and the writer to understand what is necessary in clear mathematical prose. Contrary to what one might expect, students are generally very harsh critics.

An Example

There are some problems which students will find quite easy to solve, and yet have an extremely difficult time in writing up. This situation occurs especially frequently when discussing counting problems or logic problems. The following example is taken from a popular magazine:

Mr. English, Mr. French, and Mr. Lapp all went on vacation recently--one to England, one to France, and one to Lapland. If only one of the following four statements is true, who went where?

1. Mr. Lapp went to England.
2. Mr. Lapp did not go to France.
3. Mr. English did not go to France.
4. Mr. English did not go to Lapland.

Wiswell, Philip, "Travel Fever - Three Vacations" Games Magazine (Playboy Enterprises: Vol. 6, No. 4, 7/8, 1982.)



Many students will probably be able to solve this in short order. But they will find the solution very difficult to write up. Even though they have already followed the logic of the problem, their first written attempts will be incorrect, and their second will be tedious. This situation can be very frustrating. Students should get used to dealing with frustration before they face it in their individual work.

One way to write down the solution is as follows:

We first determine which of the statements is true. Since (1) implies (2), (1) must be false. Now if (3) is false, then (2) is true, so either (2) or (3) is the true statement. In either case, (4) is certainly false. But if (4) is false, then (3) is true, and (2) must be false. Now we can determine the actual trips taken. Since (2) is false, Mr. Lapp went to France. Since (4) is false, Mr. England went to Lapland. Hence Mr. France must have gone to England.

This type of problem is important to work on for several reasons. It helps students understand the logical concept of an implication. It is a refreshing change from the more usual mathematical situations encountered. And it gives them very good practice in formally presenting a result which they have already thought out.

Some Specific Techniques of Mathematical Exposition

Mathematical prose has its own peculiar cadence. It is usually more concise than other writing. It is broken up by equations, tables, and diagrams. Rules of punctuation and grammar are often not easy to apply (two plus two are four? is four? make four?). Students need to get used to the conventions of mathematical exposition. There are unfortunately few references on writing mathematics. The book by Halmos (see bibliography) is only a start. Below are some rules for students in learning to express themselves mathematically:

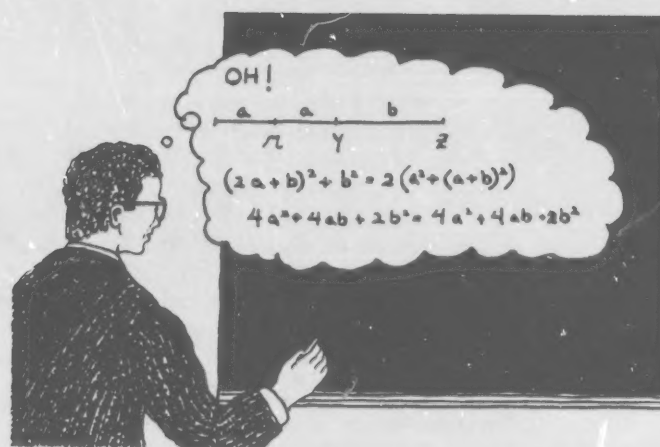
Rules for Students' Writing Style

1. Write an equation, not a sentence. Older books, particularly geometry texts, state all results in grammatical sentences. More recently, the style is to assign variables and state the results algebraically.

Example: (Older style). If a straight line be bisected, and a straight line be added to it in a straight line, the square of the whole with the added straight line and the square on the added straight line both together are double of the square on the half and of the square described on the straight line made up of the half and the added straight line as on one straight line.

Euclid, circa. 200 BC (Elements II: 10)

(More Modern Style): If X , Y , and Z are collinear, and M is the midpoint of XZ , then $XZ^2 + ZY^2 = 2(XM^2 + MZ^2)$.



2. Make clear the connection of each sentence with the preceding sentence. This is a good rule for any writing, but is especially crucial in mathematics. Students are often struck by the seeming overuse of the word "indeed" in mathematical texts. This word is used as a logical marker: it shows that the sentence preceding the word is a consequence of the sentence following. Other logical markers, such as "because," "since," "for," "whenever," and, of course, "if" are more common in mathematical writing than in other prose. Beware the use of the comma as a logical marker. When combined with mathematical symbols, this small punctuation mark can cause much confusion.

Example: Since $a=b$, $a+1 = b+1$ (not too bad)

Since $a=b$ and $c=d$, $a+c = b+d$.
(Hard to read, unless you are already familiar with the result.)

Since $a=b$, $b=c$, $c=d$, and $d=e$, $a=e$.
(Can you make sense of this?)

3. The reader must be able to tell exactly where a proof ends. The classical writers used the abbreviation "Q.E.D." (quod erat demonstrandum, or "What we wished to prove"). This is no longer used, but something must be put in its place. Some publications use the symbol "■". You may choose to use this, or to make the end of a proof clear in the text. But without some such provision, the reader is sure to be confused.

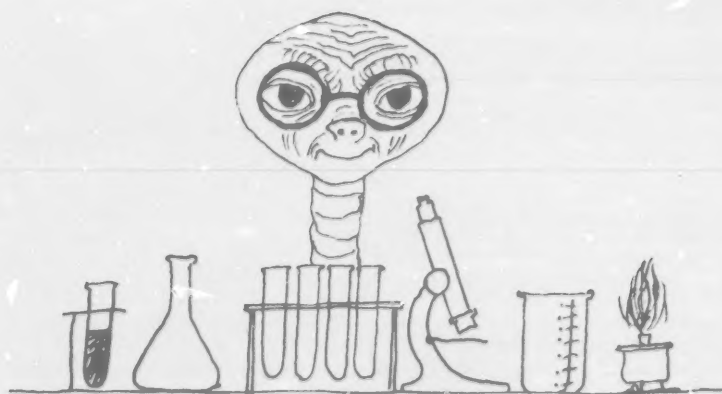
Once the technical aspects of writing mathematics are mastered, and after individual research is completed, students will be faced with the problem of organizing their paper. This is a less difficult task in mathematics than in other areas. Part of the organization of the paper is implicit in the logic of the results. The following set of guidelines may be given to students.

Guidelines for Students in Organizing the Paper

- a. Include an introduction which briefly summarizes the importance of the discussion, points out the nature of the results achieved, and tells what knowledge is assumed on the part the reader.
- b. Give a clear statement of the theorem you will prove before its proof is presented. Some writers will present a discussion, and then say, "We have proved Theorem 2... [followed by a statement of the result]." This procedure should be used with great caution. Unless the result is extremely elementary, it should be stated first so that the reader knows the direction the discussion is taking.
- c. Separate out self-contained parts of the proof as lemmas. Like subroutines in programming, lemmas (usually presented before the main result) make the flow of the proof much clearer. This is especially the case when a lemma is "called" more than once in a proof or series of proofs.
- d. Include discussion "around" the proofs, which links the results together and tells how each is important.
- e. Provide "documentation" for computer programs. In most cases, the actual program need not be listed in the text. It often suffices to give an explanation of what the program accomplishes. Sometimes the structure of the program must be discussed. But if the computer is used as a tool in the investigation, rather than as a central focus, this discussion can be relegated to an appendix along with the actual listing.
- f. Provide a final section summarizing the results achieved and indicating possible directions for future investigation.
- g. Include a bibliography containing sources referred to in the text and also other possible sources.
- h. Decide which tables and diagrams are essential for the reader's understanding, and keep these in the main body of the paper. Other diagrams and tables, and listings of computer programs, should be placed in an appendix.

6.

TEACHING LABORATORY SKILLS



Introduction

Research projects in the social sciences can be conducted quite satisfactorily by mastering an understanding of library skills and the accepted written format. Obviously these skills are inherent in science research but must be supplemented by the acquisition of laboratory skills required to safely and effectively conduct the science experiment.

This chapter lists those skills which are vital in conducting a scientific investigation. Such skills frequently relate to biology, chemistry, and physics and may be considered interdisciplinary in nature.

A biology laboratory manual may very well include skills and techniques that are found in various physical science publications. For instance, the proper use of a Bunsen burner has inherent value for all the sciences. The use of the microscope, once held in esteem as the sole property of the biologist, now is a needed tool in a variety of disciplines. The engineer, for example, will study electron micrographs of stress boundaries of various alloys. The information the engineer obtains will permit him or her to suggest alloys that are most suited for a particular task. The chemists may use the microscope to investigate crystal growth. The geologist may seek clues in strata that signal the presence of valuable ore or fuels. This section is intended to provide an overview of the skills and techniques the researcher may need in his or her individual experimental designs. However, this section will not include specific laboratory lessons for teaching these skills. Most laboratory manuals devote adequate space to lessons concerned with skills acquisition. But it is strongly suggested that the first term of science research be structured to permit your students to develop as many skills as possible.

Keep in mind that many highly individualized projects will be conducted concurrently. Time will be occupied in providing adequate laboratory supplies for individual students. Supervising the entire class may make it difficult for the teacher to work individually with students in teaching the preparation of solutions or the use of the microscope. Teaching and testing for the acquisition of laboratory skills during the first semester will permit a much smoother and safer research program.

Laboratory Safety Guidelines for Students

1. Safety glasses or goggles must be worn at all times.
2. Laboratory aprons or coats will protect clothing.
3. Long hair should be tied back or otherwise confined.
4. Hands and arms should be washed thoroughly before leaving the lab.
5. The teacher must be notified in the event of an accident or personal injury.
6. A sense of seriousness must be displayed in the lab. "Horseplay" is prohibited.
7. Keep drawers closed and aisles free of obstructions.
8. Eating, drinking, or chewing gum are strictly prohibited.
9. Avoid direct contact with all chemicals.
10. Never return any excess chemical to a "stock" bottle.
11. Never taste or smell a chemical unless specifically instructed to do so.
12. Clean up chemical spills and/or broken glassware with extreme caution. The teacher should be told of any breakage or spill prior to your cleaning up the accident.



Teacher Checklist

for Structural and Safety Features in the Laboratory

The following safety equipment must be available in the laboratory. The location of each item should be known by students. The operation of each safety apparatus should be demonstrated:

- . first aid kit
- . safety shower
- . eye wash fountain
- . fire blanket
- . fire extinguisher
- . fire alarm
- . fume hood
- . telephone

Phone numbers for the following agencies should be easily accessible to the instructor:

- . ambulance
- . fire department
- . school security
- . hospital emergency room
- . poison control
- . police

Laboratory Skills Needed for Research in Biology

Although it is not the function of this guide to spell out the specific procedures one would have to teach students to function in a research laboratory, still it is appropriate to emphasize some procedures basic to biology research.

One of these is the study and maintenance of living things in the laboratory. Before one can study the effects of aldehydes upon the population density of Euglena gracilis, one must know how to culture this organism in a "normal" laboratory environment. The preparation of the medium needed to culture Euglena involves skills one normally associates with chemistry such as (preparation of solutions) and physics (proper determination of mass). When the preparation of the modified Klebs solution is completed, the student must be able to inoculate the new medium with Euglena. If an axenic culture is required, a knowledge of sterile technique is a must. Once the Klebs solution is inoculated, the student must be able to follow the growth of the organism in the subculture. Here, a knowledge of population dynamics and the microscope play an important role. By the time the student is ready to perform the study of the effects of aldehydes on population density of Euglena gracilis, skills involving biology, chemistry, and physics have been acquired and utilized. The specific skills each student will use will vary with the organism being studied. It is very important that the research teacher provide all students with a set of basic laboratory skills that they will need to function. As projects develop, the student with the teacher will acquire skills that are specific for the successful completion of individual research projects.

Safety Rules and Procedures

The set of general safety rules and regulations set down earlier in this chapter will be in effect in the biology laboratory. In addition, the following should be reviewed before students function independently in a biology laboratory.

1. Proper care and maintenance of microscopes.
2. Procedures for cleaning glassware.
3. Procedures for proper use of analytical balance.
4. Knowledge of the safety precautions used in handling the autoclaves.
5. Complete knowledge of sterile technique.
6. Maintenance of a tidy work area (leave things the way they are found - CLEAN!).
7. Remembering the Golden Rule -- WHEN IN DOUBT, ASK THE TEACHER!

Handling Microscopes

All students coming into a biology research program have probably worked with a microscope. The teacher should quickly review general microscope procedures and teach the use of the oil immersion objective. The following skills should be emphasized:

1. cleaning of lenses and mirrors
2. use of all the parts of the microscope
3. focusing precautions
4. preparation of wet mounts
5. simple staining technique
6. observing prepared slides
7. use of the mechanical stage
8. handling the dissecting microscope.



Handling Glassware

In addition to the procedures reviewed earlier the following should be covered:

1. cleaning glassware in dichromate solutions (caution!)
2. preparation of capillary tubes and micropipettes (6-mm or smaller glass tubing)
3. sterilizing glassware
4. various techniques for stoppering flasks and bottles

Autoclave

Each student must become familiar with sterilizing apparatus and should know the theory behind sterilization using steam under pressure. The proper use of the autoclaves in the biology research lab must be reviewed and tested. Students should be instructed to shut all systems down if they suspect a problem and then inform the instructor.

Solutions

Specific reference should be made to the role buffers play in the maintenance of a living system. Students should be familiar with the theory behind buffer action. Students should be taught acid-base theory, pH scale, and the use of the pH meter. Time should be devoted to the precautions one should use when dealing with potentially toxic chemicals. It is important for all students to be aware of the special procedures used when preparing PPM (parts per million) and PPB (parts per billion) solutions.

Analytical Balances

Many projects will involve the use of the analytical balance. Time must be devoted to familiarizing students with the following:

1. when to use an analytical balance;
2. precautions to be followed when using the analytical balance (found in the instruction manual for the particular balance you have in your school);
3. storage of reagents massed on the analytical balance;

Colorimeter

One of the most powerful tools used in a quantitative analysis lab is the colorimeter. This instrument can measure concentrations of materials in the parts per billion (ppb) range. The Spectronic 20 colorimeter can be used to measure concentrations in the parts per million (ppm) range. Many projects involving environmental pollution, production and uptake of specific compounds can be designed around the use of the colorimeter.

Students should be taught how to prepare a standard curve, and then given a series of unknowns to identify. The use of the Spectronic 20 as a nephelometer for determining population densities of certain microorganisms can be studied. In addition, its use in chemical kinetics studies is unsurpassed for high school students.

Separation of Compounds

Students should be familiar with the various methods used to separate individual compounds or groups of compounds. Time should be devoted to the following:

1. use of separatory funnel
2. chromatography
3. electrophoresis

Use of the Hemocytometer

The hemocytometer or counting chamber was developed originally for counting cells in the blood. The chamber consists of a microscope slide with regularly ruled "chambers." Each chamber holds a known volume of liquid. By counting the cells in this known volume, the population of the whole culture may be estimated.

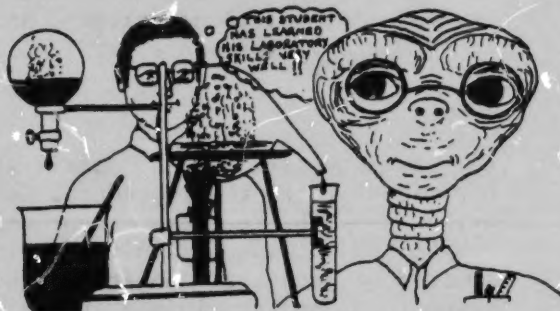
Dissecting Techniques

Teach the use of various dissection tools such as the scalpel, scissors, dissecting pins, and probes. Many experiments in biology require dissection of plant and animal specimens for examination purposes.

Microbiological Techniques

The guidelines provided by the New York City Board of Education and the New York State Department of Education restrict the use of vertebrates in high school experimentation. Thus bacteria and other microbes are becoming the preferred organisms for high school research. Some of the techniques to be taught in studying these organisms include:

1. culturing the organism, including the preparation of media and inoculation;
2. techniques for studying, counting, and disposing of the organism;
3. techniques for sterile transfer -- and the use of a sterile chamber (if available).



Laboratory Skills Needed for Research in Chemistry

1. inserting glass tubing or other items, (thermometer, glass funnel, etc.) through a rubber stopper;
2. transferring liquids from a reagent bottle, or from one beaker to another;
3. dispensing a solid from a stock bottle;
4. decanting a liquid from a solid;
5. use of filter paper and filter funnel;
6. heating liquids: test tube; Erlenmeyer flask; beaker;
7. using a pipette;
8. testing for odor;
9. procedures for "filtration";
10. techniques for proper use of a centrifuge;
11. using the fume hood;
12. using and interpreting metric rulers, thermometers, graduated cylinders.

In addition to the basic skills listed, consideration should be provided for the following specific laboratory lessons:

- . making solutions of varying strengths;
- . identification of solutions as acid or base -- and proper handling of these solutions;
- . working with glassware and tubing:
 - a. cutting glass;
 - b. fire polishing;
 - c. making a capillary tube or tip;
 - d. bending glass

Laboratory Skills Needed for Research in Physics

Use of the following instruments:

- . the voltmeter
- . the ammeter
- . galvanometers
- . rheostats and resistance coils
- . radioactivity detection instruments

Obtaining data in most physics experiments requires making measurement. The instructor should provide exercises that emphasize calculations, errors, and deviations, and graph construction. These are invaluable skills in all research.

Caveat

Care must be taken not to permit students to conduct any experiment until the procedures and techniques have been approved by the teacher. Unauthorized experiments, or variations on experiments that have not been approved are sources of potential danger. These conditions must be discouraged and prohibited at the outset.

Teaching Problem-Solving for Research

Most students entering a mathematics research program have a very primitive notion of the nature of mathematical thought. They think of algebra as a set of "things to do" to both sides of an equation to get the "right answer." They conceive of geometry as a list of steps in columns, somewhat like double-entry bookkeeping. The highly formal expositions students have had in a regular class serve to deliver information very efficiently, but they often cover up the deep thought that produced them. In order to solve new types of problems students will have to let loose their intuition.

It is often not easy to pry students loose from the security of the formal language they are used to. Once this is done, it is more difficult still to get them to come back to a formal mathematical style, after having achieved some insight of their own. But this is just the process they will have to go through if they are to do independent research in mathematics.

There are many approaches to the teaching of this process. In most cases these involve a radical departure from the usual norms of traditional classroom teaching. The student must be made comfortable with the idea that he or she can think through a problem independently, and need not rely on the teacher to find the next step. Even more difficult is the realization, which must eventually come, that the student is the judge of which approaches are yielding results, and cannot depend on the teacher for constant approval of his or her progress.

Teachers, too, often find it uncomfortable to be in front of a class without knowing all the answers. One cannot expect to know every detail of every topic discussed with the class. In fact, when students ask original questions that the teacher may have trouble answering, the mathematics research class is most successful. Teachers will find that students still respect a teacher's experience, leadership, and judgment, even if they can "stump" that teacher with difficult questions.

A Sample Group Project

The following typical class project may be worked on in various contexts.

Denote by a_n the integer closest to n , for $n = 1, 2, 3, \dots$

Find the sum

$$\frac{1}{a_1} + \frac{1}{a_2} + \frac{1}{a_3} + \dots + \frac{1}{a_{1980}}$$

1 = 1	$a_1 = 1$
2 = 1.414	$a_2 = 1$
3 = 1.732	$a_3 = 2$
4 = 2	$a_4 = 2$
5 = 2.236	$a_5 = 2$
6 = 2.449	$a_6 = 2$
7 = 2.645	$a_7 = 3$
8 = 2.828	$a_8 = 3$
9 = 3	$a_9 = 3$
10 = 3.162	$a_{10} = 3$
11 = 3.316	$a_{11} = 3$
12 = 3.464	$a_{12} = 3$
13 = 3.605	$a_{13} = 4$
14 = 3.741	$a_{14} = 4$
15 = 3.872	$a_{15} = 4$
16 = 4	$a_{16} = 4$
17 = 4.123	$a_{17} = 4$
18 = 4.242	$a_{18} = 4$

Example 1

It generally does not work, at least in a preliminary session with students, to write a problem on the board and then say "Go and solve it among yourselves." The students first need to be made aware of exactly what the problem is that is being posed. Terms have to be defined. Notation must be explained. Sometimes, the teacher must go through a preliminary result with the class, which will enable them to solve the problem.

In the case posed above, before throwing open the discussion, or even presenting the full problem, most students will need to get used to the notion of a subscript. Here, they need only be asked "What is a_1 ?" ($a_1 = 1$). Some students will see the answer right away. Even if they do, they should then be asked about a_2 , a_3 , and so on, until they can begin constructing their own table, such as that in Example 1 to the left.

The calculation of a_6 and a_7 presents a subproblem. Most students can remember the approximate decimal value of $\sqrt{2}$ and $\sqrt{3}$. They know that 4 is a perfect square, and 5 is close enough to 4 to see that a_5 is "still" 2. But is a_6 equal to 2 or 3? An obvious way out is the use of any calculator with a "square root" key. Students can use this machine to get the $\sqrt{6}$ to somewhat more than the accuracy needed to find a_6 .

Note:

If a calculator is not available, however, there is an alternative method to settle the question. We want to know, if $\sqrt{6} < 5/2$. Now most students will already know, or will readily accept the fact that

$$0 < a < b$$

if and only if $a^2 < b^2$ (that is, squaring or extracting positive square roots preserves the order of an inequality between two positive numbers). Thus we can test whether the statement $\sqrt{6} < 5/2$ is true by seeing if $\sqrt{6}^2 < (5/2)^2$.

Since $\sqrt{6}^2 = 6$ and $(5/2)^2 = 25/4 > 24/4 = 6$, the second statement is clearly true, so the first one is as well, and $a_6 = 2$.

This argument is not really so simple: there are a number of hidden fallacies which it neatly avoids. To go too deeply into this subproblem will probably distract students from the main problem. There is time later on, when students have already appreciated the value of insight, to go back and formalize the argument.

Now most students will be ready to fill in the chart for a_1 , a_2 , a_3 , and so on. But, once they have learned to calculate the successive entries, we would like them to refrain from calculation for a while. The true mathematical spirit, seeing two 1's, four 2's, and six 3's

in the chart, will be impelled to guess that the next few entries will consist of eight 4's, ten 5's, and so on. We find that some students will not be willing, at first, to guess at the rest of the chart in an "official" classroom context. The teacher has to spend time supporting their speculative spirit.

Perhaps at this point we should discuss a little more fully the differences and similarities between natural science research and research in mathematics. In the natural sciences, there exists a well known and time-tested paradigm for doing research. This involves looking at the existing evidence about a topic, hypothesizing a solution to a problem presented, testing the hypothesis by experimentation, and writing up and disseminating the results. Although we do not make the same use of this paradigm in mathematics, we could do well to learn from it.

That is, in investigating a mathematical problem, it is often useful to put ourselves in the position of a natural scientist. We first observe the "behavior" of some mathematical objects. Forgetting for a moment that these objects are creatures of our, or someone else's imagination, we step back and watch how they "act." Our task is essentially the same as that of the naturalist--to predict how they will continue to act, or how they will act under some other circumstance, and to deduce general laws about their behavior. In doing this, we might profitably follow the same steps as the natural scientists. Our "hypotheses" are called conjectures, and our experiments are done with pencil and paper (or with computer and calculator). We are even luckier than the natural scientist in that we can actually prove our results--we can relate them to some fundamental "unshakable" assumptions. We don't have to wait years for others to confirm our experiments.

In the present case (as in the case of the natural scientist) we cannot say that we have solved the problem once we've made a conjecture. The pattern seems to be correct, but a formal proof is probably beyond all but the most sophisticated of the students, and it is not advisable to ask them to produce one at this point. Rather, we can ask them to test their hypothesis in a number of cases. Is a_{12} really equal to 3? How about a_{15} ? Or a_{21} ? If a student can verify these individual cases without recourse to the pattern he or she has guessed (that is, by calculation), the student already has some justification for his or her conjecture.

To state this conjecture formally, we can choose an integer k , and find how many other integers n there are such that

$$(1) \quad k - 1/2 < n < k + 1/2.$$

Squaring both sides of these inequalities gives the equivalent condition:

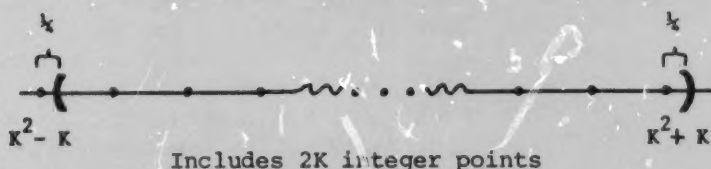
$$(2) \quad k^2 - k + 1/4 < n < k^2 + k + 1/4.$$

(This condition is equivalent to the original inequality because all the terms involved are positive.)

Now we can observe that there are as many integer points satisfying (2) as there are satisfying:

$$(3) \quad k^2 - k < n < k^2 + k.$$

(The "shift" of $-1/4$ does not change the number of integer points in the interval.) There are clearly $2k$ possible values of n which satisfy condition (3).



Having guessed, and perhaps in some way proved, the pattern emerging from the table of the numbers a_n , students are in a position to begin solving the main problem. But most students will not know what to do next. There are several possible reasons for blockage at this point. Some students may think that the problem is already solved once they have tackled the subproblem of the table. Others may see that there is a larger problem in front of them, but may not be able to find a "toehold" to begin solving.

Still other students may already be bored. Normal classroom procedure presents students with a series of questions through which they learn. But many of the questions ask for recall, rather than reflection. Even those questions which do require thought demand only a small amount of thinking at one time. This is because of the fast pace and close guidance involved in a well-planned developmental lesson. Such lessons sometimes have the unfortunate side-effect of developing a short span of concentration in students. We achieve efficient

delivery of much information at the expense of decreasing some students' ability to concentrate for longer spans of time.

Our job then is to increase the amount of time that students will be willing to work on a single problem. One way we can do this is by providing possibilities for partial achievements within the solution of the larger problem: that is, by singling out subproblems which students can deal with on their own.

In the present problem, instead of looking at the entire sum all at once, we can write out part of the required sum:

$$\frac{1}{a_1} + \frac{1}{a_2} + \frac{1}{a_3} + \frac{1}{a_4} + \frac{1}{a_5} + \frac{1}{a_6} + \frac{1}{a_7} + \frac{1}{a_8} + \frac{1}{a_9} + \frac{1}{a_{10}} + \frac{1}{a_{11}} + \frac{1}{a_{12}}$$

Then we can transform the sum, using the table:

$$\left(\frac{1}{1} + \frac{1}{1}\right) = \left(\frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2}\right) + \left(\frac{1}{3} + \frac{1}{3} + \frac{1}{3} + \frac{1}{3} + \frac{1}{3} + \frac{1}{3}\right)$$

Many students will begin to see a new set of patterns emerging. Because of the pattern from the table, the sum will contain a succession of 2's. For students who do not see this so quickly, one might ask, "What is the sum up to a_6 ? What is the sum up to a_{12} ?" and so on.

This line of questioning is also useful also to students who see the sequence of 2's on their own. We can extend this line of questioning to ask, "What are convenient stopping-places for partial sums?"

One possible answer involves factoring the numbers in this new sequence. We have:

$$\begin{aligned} 2 &= 1 \times 2 \\ 6 &= 2 \times 3 \\ 12 &= 3 \times 4 \\ 20 &= 4 \times 5 \end{aligned}$$

Students can check that the next group summing to 2 does indeed end at term $5 \times 6 = 30$, and they can perhaps see that the group after this ends at $6 \times 7 = 42$. They can then apply this insight to the original problem by rephrasing the problem. Instead of asking for the numbers of groups of terms summing to 2, they can now merely seek the largest number of the form $n(n+1)$ which is less than (or equal to) 1980. The answer to this can be found by calculator, or by hand, for $1980 = 44 \times 45$. Hence the term $1/a_{1980}$ is the end of the 44th group of terms summing to 2. The sum of the original sequence is thus 44×2 (44 partial sums of 2), or 88.

A formal proof of this conjecture is quite difficult to write. It would involve a connection between the sequence 2, 6, 12, 20...and the so-called "triangular numbers."

We have:

$$\begin{aligned}1 &= 1 \\2 &= 1 \times 2 = 2 \\6 &= 2 \times 3 = 2(1 + 2) \\12 &= 3 \times 4 = 2(1 + 2 + 3) \\20 &= 4 \times 5 = 2(1 + 2 + 3 + 4)\end{aligned}$$

This pattern is ultimately based on properties of arithmetic progressions, and the fact that $1 + 2 + 3 + \dots + n = n(n + 1)/2$. Only students with a lot of formal background will see this.

Some Notes on Group Problem Solving

The above example shows one approach to difficult mathematical problems. How one uses this or other examples will depend on a number of variables. The instructor may want to do a lot of work with the class as a whole, or may want to split the class up into small groups right away. The teacher may want to assign students to work together, or allow them to fall into their own natural groupings. All this depends on one's own teaching style and the class.

Many teachers have found that students who work in small groups on this type of problem encourage each other's creativity. Working in small groups also provides a transition from the formal classroom to the individual research situation. But small groups of students working together require skilled guidance by the teacher. Some groups will race ahead and skip over fine points in the argument. Others will stare at the problem and will need suggestions and encouragement. It is probably best to circulate and make sure that every student in the classroom is working on something appropriate to his or her level. A useful technique is to join together two or three students who are working at the same rate, or to ask two students who have a result to check their results against each other. If they disagree, one of them must convince the other of his or her answer.

The preceding example has a purely numerical answer, which is clearly either right or wrong. This is a useful quality in an introductory problem. It is easy in these problems for students to see exactly what sort of solution is required, and the existence of the numerical answer "somewhere out there" tends to spur them on. The danger

is that one quick student may get the numerical answer, and the answer may spread among the class. Students who have not had any insight may begin to parrot the answer, and not see that it requires some substantiation. The teacher can help prevent this from happening by not telling whether a numerical answer is correct until ready to end the session.



What generally happens then is that more and more students begin getting some sort of answer. Some students will get the wrong answer and some will be correct. Students should check their answers against each other. Ultimately, a consensus will be achieved among the students as to what the answer really is. At that point, the teacher may step in. This situation, in fact, resembles academic reality. Here, too, a result is often achieved intuitively, and gains acceptance slowly, as more and more people become convinced of its correctness. In the classroom, this process generates much excitement. Students begin to get answers and experience the suspense of waiting for their answers to be confirmed.

The time-scale of this problem, or any problem, depends on the background and ability of the students. Experienced problem solvers can do such a problem in half an hour or less, and even write it up in that short span of time. For students who have no problem solving experience, and/or little background in mathematics, this small problem may take several days. In research, more than in any other field, the "right" amount of time to spend is the amount of time it actually takes to achieve success. We must abandon the notion that teaching is to be measured in ideas per minute, we must let the flow of the class be governed by the students' abilities.

A third decision which must be made on the same basis is the degree of formality to be expected from the students. This is a problem which can be worked on, and understood, on many levels. Students with no knowledge of algebra can get the right answer, and learn something from getting the

answer, using only arithmetic. Students familiar with algebraic methods will be able to do more. Students who know mathematical induction can do still more. And experienced problem solvers can sometimes churn out a solution in half an hour or less, and express it in a concise and elegant paragraph. It is important, in an introductory session to see where the students are in their ability to express mathematics in formal language. Later, one can insist on more and more mathematical forms of expression.

What Are We Teaching?

There are two equally important objectives in teaching mathematical research. One objective is the teaching of general problem-solving techniques, applicable in a variety of situations. A second objective is the teaching of specific mathematical techniques, which can also be widely used, but mostly in mathematical situations. Let us look at the above example and see how these two objectives complement each other.

Specific Problem-Solving Techniques

Some problem-solving techniques which we called upon in the discussion are:

1. An examination of special cases: This can often give clues for the solution of a larger problem. We did this when we used the special cases a_1 , a_2 , etc., to help the students grasp the meaning of a_n for any n .
2. Transformation of the problem: This powerful technique can serve to reduce a complex problem to a simpler one, or can relate an unfamiliar situation to a more familiar one. An example is the recognition and use of the triangular numbers in counting the groups summing to 2. This happened in the formal proof (p. 104) of the conjecture about the table of a_n .
3. Formation of subproblems: Concentration on a small aspect of a large problem helps direct our energies in solving a problem, and prevents us from being overwhelmed by a myriad of details.
4. Statement of a conjecture: We did this several times in the discussion. A clear statement of what we need to prove becomes essential at some point. Making an insightful conjecture is one of the more difficult crafts of the problem solver.

In addition to illustrating these specific techniques, the example discussed exposes students to the peculiar parallels between mathematical and scientific methods. It also serves to stretch their span of attention. Both of these more general objectives are essential for students who wish to do research in mathematics.

In planning work with the students, examples of the use of these and other general problem-solving techniques should be woven into the discussion of more specifically mathematical skills. The area of problem solving methods is difficult to handle in the classroom. A good reference for more ideas about problem solving is the series of books by Polya cited in the bibliography.



Specific Mathematical Techniques

The following mathematical methods which were touched on in the above discussion will probably reappear in the students' research:

1. Subscripts: The example provides a good introduction to the simplest use of subscript notation.
2. Inequalities: This topic is much neglected in most algebra and geometry courses. In individual research, students will need to handle inequalities as often as equations.
3. Triangular numbers: These are good examples in a number of situations, and frequently make a "natural" appearance in an investigation.
4. Grouping of finite sums: This relatively simple technique is often overlooked by students.
5. Summing an arithmetic progression: Again, this is a frequently-recurring topic. For students on a more advanced level, the example provides an exercise in mathematical induction, one of the prized tools of the mathematician.

Some Suggestions for Mathematical Content

As one continues to explore the methods of mathematical research with the class, an outline will provide direction. This outline must be carefully prepared to meet the needs of the particular students in the class.

In the area of mathematical content, we offer the following annotated outline of topics which can be covered. This list is neither exhaustive nor prescriptive. It is best used as a sort of "menu" from which to choose topics for students. It can sometimes be a real challenge to find a problem of an appropriate level for a particular topic. But most of these topics are general enough to include problems on many different levels.

One of the most important and difficult tasks of the teacher of a mathematics research program is to amass a collection of problems and examples for various mathematical topics. This task is too enormous for us to address here. It takes years to build up a versatile repertoire of problems. One shouldn't be surprised if the first few attempts are failures. As a starting point, we have given some sources of problems on each topic.

- I. Mathematical Induction: For an exciting account of how this technique can be used both for generating conjectures and for proving them, see G. Polya's classic Induction and Analogy in Mathematics. (Princeton, N.J.: Princeton University Press, 1954.) It touches on:

- . summation of series
- . divisibility
- . geometry
- . tower of Hanoi and other puzzles
- . number theory

References:

Shklarsky, D. O., Chentsov, N.N., and Yaglom, I.M., The USSR Olympiad Problem Book. (San Francisco: W. H. Freeman, 1962).

Shklarsky, D. O., Chentsov, N.N., Selected Problems and Theorems in Elementary Mathematics. (Moscow: Mir Publishers, 1979).

Golovina, L.I., and Yaglom, I.M., Induction in Geometry. (Moscow: Mir Publishers, 1979).

Birkhoff and MacLane, A Survey of Modern Algebra. (New York: Macmillan, 1977).

II. Combinatorics: This area is important in current research. It is especially useful for our purposes, as extremely interesting questions can be posed which require little background knowledge on the part of the students.

- . permutations
- . combinations
- . tree diagrams and more complicated situations
- . combinatorics in geometry

References: Niven, I., Mathematics of Choice. (MAA, 1975.)

III. Fibonacci and Lucas numbers: These may appear at first to be an artificial construct, but they often come up in the midst of a seemingly unrelated mathematical discussion.

- . recursive definition
- . sums of Fibonacci and Lucas numbers; sums of powers of the numbers
- . the Binet formula: computation of Fibonacci and Lucas numbers from their indices
- . the golden section in geometry and art

References:

Bicknell, M., Hoggatt, J.E., Jr., (eds.), Fibonacci's Problem Book. (San Jose: San Jose University, Fibonacci Association, 1974).

Hoggatt, V.E. Fibonacci and Lucas Numbers. Boston: Houghton Mifflin Co., 1969).

IV. Pascal's triangle and binomial coefficients: Another important set of objects.

- . Factorial notation
- . the symbol (r^n)
- . Pascal's triangle
- . Identities involving binomial coefficients
- . The binomial expansion and its connection with Pascal's triangle
- . The multinomial expansion
- . Pascal's triangle and figurate numbers
- . Pascal's triangle and the Fibonacci numbers

References:

Shklarsky, Chentsov and Yaglom. The USSR Olympiad Problem Book.

Niven. Mathematics of Choice.

V. Number theory: This topic by itself could be made the basis of a substantial research course, even on the high school level. A large proportion of mathematical research on this level involves some aspect of number theory.

- a. divisibility tests in base 10 and other bases of notation
- b. Euclid's Algorithm: greatest common divisor and least common multiple
- c. the fundamental theorem of arithmetic
- d. congruences
- e. Wilson's theorem; Fermat's "little" theorem
- f. linear Diophantine equations
- g. continued fractions
- h. Farey series and Egyptian fractions
- i. partitions of integers
- j. magic squares

References:

Dudley, U., Elementary Number Theory, (San Francisco: W.H. Freeman, 1978).
Hardy, G.H. and Wright, E.M., Introduction Theory of Numbers, (Oxford: Oxford University Press, 1980).
Sierpinsky, W., 250 Problems in Elementary Number Theory (Netherlands: Elsevier, 1970).

VI. Transformations and geometry: This provides a refreshing approach to a subject that some students have come to think of as dry.

- . translations
- . rotations
- . line reflections
- . dilation
- . spiral similarity
- . projection

References:

Yaglom, I.M., Geometric Transformations, Volumes 1, 2, 3.
(MAA, 1975, 1979).
Coxeter, H.S., Greitzer, S., Geometry Revisited, (MAA, 1975).
Modenov, P.S., Parkhomenko, A.S., Geometric Transformations, (New York: Academic Press, 1965).

VII. Geometry: As noted above, students have a poor conception of this area. Since we normally use it to teach formal proof, many students do not see how intuitive the subject can be. We can show them this by extending their knowledge in certain directions.

- . loci--circles of Apollonius
- . the triangle: medians and altitudes
- . the triangle: angle bisectors; inscribed and escribed circles
- . the triangle: circumcircle and the extended law of sines
- . the medial triangle and the Euler line
- . the nine-point circle
- . the orthic triangle: an introduction to geometric inequalities
- . transversals: Ceva's and Menelaus' theorems
- . cyclic quadrilaterals and Ptolemy's theorem
- . inversion in a circle

References:

Altshiller-Court. College Geometry
Coxeter and Greitzer. Geometry Revisited

VIII. Sequences and series: Arithmetic and geometric progressions come up quite often. The notion of convergence can be introduced in a natural fashion.

- . arithmetic, geometric, and harmonic series
- . summation of finite series
- . convergence and the summation of infinite series

References:

Hall, H.S., Knight, S.R., Higher Algebra (London: Macmillan, 1957).
Chrystal, G., College Algebra (New York: Chelsea, 1952).
Knopp, K., Infinite Sequences and Series. (New York: Dover, 1956).

IX. Group theory: This provides an opportunity for students to develop their ability to work with abstractions.

- . definition of a group
- . examples of groups in algebra and geometry
- . theorems about groups
- . Isomorphism
- . Group theory and number theory

References:

Birkhoff and MacLane. A Survey to Modern Algebra
Grossman I., and Magnus, W., Groups and Their
Graphs. (MAA, 1975.).

- X. Theory of equations: This area provides numerous applications and examples of all of the above techniques.

- . symmetric functions of the roots--algebraic symmetry
- . sums of powers of the roots--Newton's formulas
- . transformation of equations
- . solution by radicals--the general cubic and quartic equations

References:

Hall and Knight. Higher Algebra
Burrows, W.S. and Panton, A.W. Theory of
Equations. (New York: Dover, 1960.).

- XI. Inequalities and Maximum-Minimum Problems: These areas are becoming more and more important in current research.

- . inequalities and means: arithmetic, geometric, harmonic
- . maxima and minima: algebraic considerations
- . geometric inequalities

References:

Beckenbach, E. and Bellman, R. An Introduction to
Inequalities. (New York: Random House, 1961).
Kazarinoff, N.D. Geometric Inequalities. (New
York: Random House, 1961).

In addition to this list, include various non-mathematical or semi-mathematical materials as resources. These puzzles or diversions and "brain-teasers" can provide both a good introduction to certain mathematical methods and can also serve to enliven the classroom discussion by breaking up the formal discussion.

References:

Kraitchik, M. Mathematical Recreations. (New
York: Dover, 1953).
Schuh, F. The Master Book of Mathematical Puzzles
and Recreations. (New York: Dover, 1969).
Frohlichstein, J. Mathematical Fun, Games, and
Puzzles. (New York: Dover, 1962).

8.

STATING THE HYPOTHESIS

What Is an Hypothesis and How Does It Assist in Experimental Design?

After the student has reviewed the literature, and is somewhat familiar with the background information relating to the topic, it is time to formulate an "educated" assumption as to the anticipated results for the project. The "hypothesis" has been described as the researcher's link between the set of conditions (variables) existing in an experiment and the expected results.

Consider the hypothesis: "Penicillin is an effective antibiotic for treating diseases caused by Staphylococcus aureus." In this situation we are proposing that if Staphylococcus aureus is exposed to penicillin, then the organism will be killed. This working hypothesis will provide us with the foundation for designing the experiment. In this instance we would expose Staphylococcus aureus to penicillin and collect data on the results of this exposure. If the organism is killed, then we may say that our hypothesis is supported. However, if Staphylococcus aureus is not killed, the data will not support the hypothesis. Still another possibility exists: some organisms may be killed, but not the entire culture. In this case, we have neither supported nor rejected the hypothesis but have modified the hypothesis.

We may summarize this phase of the research project as follows: information gathered through readings prompts a problem statement; a hypothesis is formulated to answer the question; and finally an experiment is designed to test the hypothesis.

Formulating the Hypothesis

In order to state a hypothesis, the researcher generally makes a number of assumptions. The assumptions or premises on which the hypothesis is based are called postulates. It should be noted that an observable phenomenon may have more than one hypothesis. Multiple hypotheses are common in science, and represent separate situations that can be tested by other research teams.

In formulating the hypothesis, it is suggested that the student maintain a point of reference linking the independent variables with an expected result. Many texts refer to this thought process as the "if" A..., "then" B procedure.

Coal Miner's Disease

Observation: Coal miners often develop lung diseases such as emphysema.

Correlation: If a miner works in a coal mine for a period of time, then he or she will develop diseases of the lung.

Hypothesis: Prolonged exposure to coal dust results in lung disease.

The researcher may now structure a series of experiments to prove the validity of the hypothesis. For example, he or she:

- a. may expose a group of laboratory animals to coal dust;
- b. conduct a survey among miners to establish a correlation between the period of time they worked in a coal mine and the presence or absence of lung disease.

The postulates or assumptions based on background readings that preceded the hypothesis statement may have been:

- a. Foreign particles entering the lungs can cause disease over a period of time.
- b. The lungs are not able to safely remove coal dust particles without becoming damaged.
- c. When sufficient lung tissue is damaged, the resulting disease becomes irreversible.

Modifying the Hypothesis and Planning for Further Investigations

It would be unusual if a problem in science could be solved in one research experiment. The results will often suggest additional investigations. In the coal miner example, the survey may determine that many coal miners do indeed develop lung disease. However, others exposed to primarily the same conditions do not develop lung disease. Furthermore, more coal miners get lung disease than people in the general population. Has the hypothesis been supported? Not entirely, but one can modify the statement to reflect the results as follows: "The percentage of coal miners who develop lung disease will be greater than that of the general population".

Additional suggested investigations may include:

- . Why are the lungs of some coal miners free of disease?
- . What is the relationship between tobacco smoking and coal miners' lung disease?
- . Can a filtering device be designed that will be comfortable to wear while reducing potentially hazardous coal dust particles?

Weathering of Wood

Suppose the student is interested in finding out how sunlight affects untreated wood. The student will research the literature for the properties of "wood" and an understanding of the components of sunlight, e.g., ultraviolet radiation. The student may have read that many paint manufacturers stress the ability of their product to filter or block ultraviolet radiation and thus preserve the wood from this weathering process.

One possible hypothesis suggested by the problem may be that untreated (e.g., not painted or pressurized, etc.) wood will weather faster when exposed to sunlight than "treated" wood. The data will most likely support a portion of the hypothesis but will suggest other possible investigations such as:

- . Do all types of wood weather at a constant rate?
- . What paint products and colors are most effective in preventing weathering?
- . How does pressurized wood treatment compare to conventional painting in regard to weathering?



Summary

The hypothesis statement or explanation suggests a prediction that can be observed or tested under experimental conditions. The scientist avers that theoretically the conditions stated in the hypothesis are true and can be proven. The scientist then proceeds to design an experiment that will link up the variables contained in the equation, if "A"... then "B." The results, related to the hypothesis, either proved or disproved, lead to further investigations.

9.

DESIGNING AND IMPLEMENTING THE RESEARCH PROJECT



PART I — SCIENCE

Planning the Investigation

The science project begins with a problem statement and a review of related literature. The investigator expresses a hypothesis and proceeds to design an experiment that will yield data to support the hypothesis. The data is then interpreted and a conclusion stated.

This section concentrates on the steps that may be taken in designing a detailed experiment. Unfortunately, there is no single "recipe" that will satisfy every conceivable problem. However, there are certain guidelines that should be adhered to in order to provide the researcher with the most reliable information for the investigation.

The Controlled Experiment

In a controlled experiment the same procedure is performed twice. All the conditions are as much alike as possible except that one factor, the variable, is changed in one set of experiments. For example, if the student wishes to determine the effect of an antibiotic on a particular strain of bacteria, the student may design an experiment as follows:

1. Culture bacterium (x) in nutrient agar at 37°C (the control).
2. Culture bacterium (x) in nutrient agar at 37°C and antibiotic y the variable.

If the results in the two experiments differ, then the researcher may conclude that the difference(s) are due to the variable. It should be noted that if more than one variable is used, e.g., addition of a chemical and a change of temperature, no conclusion may be stated about a single variable without reference to the second.

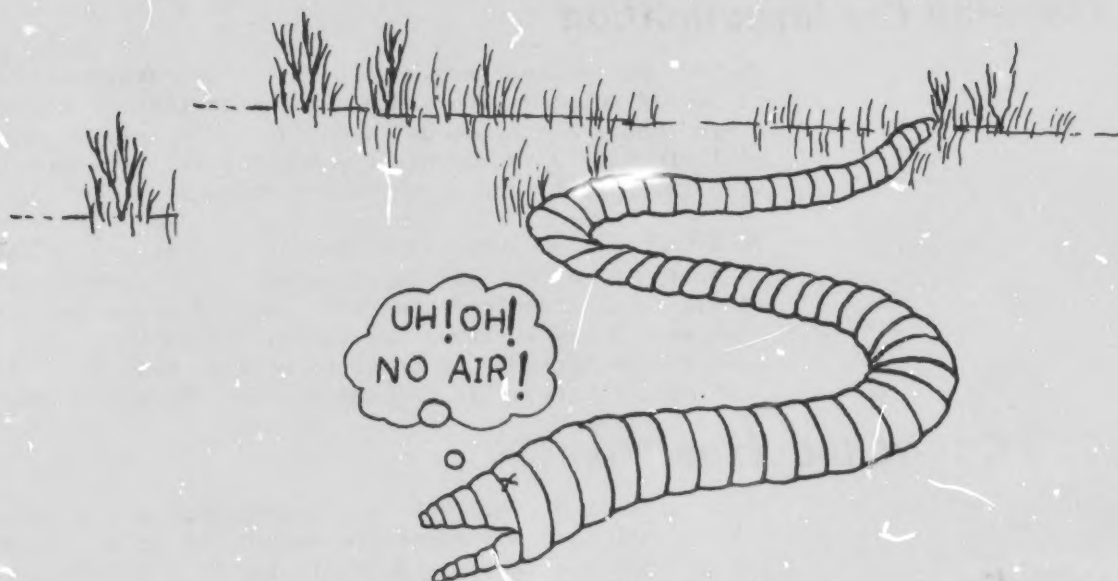
Designing the Experiment

Select organisms or conditions that are relatively easy to handle or control and will give reliable data.

Cost and time are factors which also must be considered. Drosophila (the fruit fly) is an ideal organism for genetics experiments because of its relatively short life span; easy storage maintenance (hundreds may be kept in a 3 or 4 inch vial); and low-cost maintenance (prepared media are pennies per culture vial).

Special consideration must be given to the experimental variable. The variable cannot be selected randomly without concern for the organism or condition to be studied.

Exposing earthworms in an anaerobic (without air) environment results in "dead" earthworms. The experiment



is not contributing to new science knowledge. The results are exactly as predicted in the literature. More important, it reflects a senseless, inhumane experimental condition. However, exposing earthworms to different soil strata may result in data useful to an industry that raises earthworms as fishing bait. The ideal experimental condition limits the situation to a single variable. However, unplanned variables always enter the experiment.

Suppose that the student is investigating the growth of "bean plants" in three pots, each containing a different type of soil. Analysis of the results may be questioned regarding variables not planned for in the original design. For example, did all of the plants receive the same intensity of light? Were temperature and/or air currents identical in all three plants? Did each plant receive the same amount of water?

With practice, the researcher will learn to anticipate these problems and to plan for them accordingly.

Simplicity of apparatus is much more desirable than setting up a complicated array of glassware, tubings and measuring devices. Although sophisticated measuring apparatus may be needed for exploring certain phenomena (e.g., electron micrography, spectrophotometer, autoradiography), most experiments may obtain adequate results with a simplified design. Indeed the foundations of modern genetics were provided by T.H. Morgan and his associates at Columbia by culturing fruit flies in pint glass containers. When the design of the experiment and selection of material is too complicated, the experimenter may find that an excessive amount of time is spent on maintaining the material rather than in obtaining data.

Student Checklist for Planning the Experiment

1. List all of the materials, equipment, supplies and organisms that will be needed. Be as specific as possible. For example, if you intend to use test tubes, specify the size and type; for example, 50 mm - pyrex.
2. Establish all laboratory techniques. If you are to use an analytical balance you should have received instruction in the proper care, maintenance, and use of this instrument.
3. Plan to properly record and interpret the data. Will the data be recorded in a log? Will it utilize graphs? Will a computer be used to store the data?
4. Determine how long the investigation will take and realistically allot adequate time for observations and maintenance of the organism and/or experimental condition. Consider school holidays and summer recess. If necessary, your teachers may make arrangement with the school principal and custodian to allow you to make observations or care for organisms at times when the school is officially closed.
5. Make sure adequate space has been assigned to conduct the experiment. Some students may prefer to conduct the experiment at home. They may feel that they have more space available, and can budget their time more productively.



The teacher is responsible for supervision of the work. Thus, a student working with particularly hazardous or toxic chemicals should not be permitted to do the work at home.

A Message to Biology Teachers

The selection of an organism for experiments in biology must be done with the utmost of care. In all laboratory investigations, animals must be treated humanely. Providing them with clean culturing areas, food, water and other necessities of life must be the prevailing attitude in biology experiments. Neglecting plants, e.g., allowing them to wilt or become diseased, likewise will result in rendering them useless for experimentation.

In general, biology experiments should be conducted on invertebrates such as bacteria, protozoa and insects. Most basic biological processes and information can be adequately revealed through the use of these organisms. Vertebrate experiments on living animals should not be conducted with the exception of

- a. observations of normal living patterns of wild animals in a zoo, or pets at home.
- b. the use of surveys and questionnaires for experiments in psychology or sociology.

The guidelines provided by the sponsors of the Westinghouse Science Talent Search and the New York City science fairs reflect the aforementioned statement, but allow vertebrate experimentation if conducted under the direct supervision of a properly certified scientist. The science fair sponsors require a signed affidavit to reflect this direct supervision.

In either case, vertebrates may not be displayed in exhibits at science fairs.

Problems Involved in Carrying Out an Investigation

Towards the middle of the first term of a science research program, students will have acquired the basic library and laboratory skills. They have been culturing an organism if they are involved in biological science, or performing a similar activity if they are involved in the physical sciences. Attention is now directed towards the design and implementation of a research project. The research teacher is about to become a research advisor because group studies have been completed and individual project planning begins. The success or failure of a student's project rests on the ability of the student to locate a problem and the ability of the instructor-advisor to channel student energies in a direction that will give the best possible chance for success. There are a number of processes that the students must experience on the way to designing and implementing a research project--stating the problem, locating background information, designing workable materials and methods, updating and refining the experimental process and, finally, performing the experiment.

Stating the Problem and Locating Information

After working with an organism or a chemical or physical phenomenon, students begin to "think" about a problem to investigate. Library visits are made to search the literature for "ideas." Students discuss their research with the advisor and a "tentative" problem is stated. For example, a student has become interested in the mating processes involved in the reproductive cycle of Drosophila melanogaster. A series of ongoing meetings are held and the researcher and advisor agree that the problem is too general. After a period of time, the problem is restated as: "The effects of the visual stimulus of the wing vibrations of male flies on the courtship success of Drosophila melanogaster males." Now that the problem has been stated, the student begins an independent investigation of the courtship process. This investigation involves searching the literature for experiments performed in this area and refining culturing techniques to determine if courtship behavior can be observed. If all goes well, the student is ready to move on to the next step in the process -- designing a procedure.

Materials and Methods

The success of a research project is dependent on the designing of a workable procedure. Students will research the literature and find procedures that will produce results. The advisor must work closely with the student

to insure that a workable design is being created. The physical plant, available equipment used to produce a workable procedure, cost of materials, time for experimental runs, and the need for setting up an "at home" mini-laboratory or locating a college or hospital lab must be considered.

THE PHYSICAL PLANT

An analysis of the high school laboratory must be performed to determine if the research project can be performed "in-house." Factors such as temperature variations, electrical supply, water supply, use of other science classes, and interference from other on-going research projects must be considered.

AVAILABLE EQUIPMENT NEEDED TO PRODUCE A WORKABLE PROCEDURE

Most projects can be performed in the high school laboratory, equipped as set forth in Chapter Six. The success of a project is greatly enhanced if design is simple and the need for the use of a college or hospital lab is minimized. If inexpensive (under \$100.00) equipment is necessary, it may be purchased. Keep in mind that equipment purchased for one project will be used in a future project. Thus over a period of time, the lab equipment inventory will grow. For example, if a particular procedure involves the measuring of light intensity, a foot-candle meter can be purchased. The student(s) doing the project will use the meter and when the work is completed, the meter becomes part of the laboratory inventory. (Note: As time passes and the program grows, finding storage space for this special equipment may become a problem.)

If the equipment needed is too expensive to purchase or have made, a modified version might be built by the researcher. For example, the researcher who worked on the Drosophila courtship project could have purchased special observation cells. This would have involved a significant investment. The problem was resolved by the researcher building the observation cell using a watch glass, cheese cloth, needlepoint canvas and alpha cyanoacrylic adhesive (Krazy Glue).

COST OF MATERIALS

Projects may have a simple design, but they may involve the use of large quantities of inexpensive reagents, small quantities of expensive reagents, large quantities of expensive reagents, etc. Before a project can begin, a cost analysis must be performed and funding for the purchase of perishables must be arranged (Chapter Two discusses funding in detail).

For example, a student's research procedure might involve the determination of urea and ammonia nitrogen concentrations. This assay can be performed using a Spectronic 20 colorimeter. A problem develops when one finds out the price of the EDTA, phenol-nitroprusside, alkaline hypochlorite and Type VI urease (activity 3400 units/gram). Unless funding is arranged in advance, cost factors may prevent this research project from proceeding.

TIME FOR EXPERIMENTAL RUNS

The time required to run a particular procedure must be evaluated before a project can begin. Most of the "bugs" involving time can be worked out before the start of a project. Unfortunately, the best planning can't determine when Murphy's Law will strike. Thinking about time will enable the researcher/advisor team to resolve "Murphy" interruptions successfully. A flow chart of a scientific procedure will eventually evolve from the above-stated process. The time to make "experimental runs" must be planned around the student's school program. (Note: It is suggested that the research class be programmed during first or last periods so that students can come to school early or stay late.) Therefore, logical breaks or stopping points in a procedure must be determined.

As indicated earlier, a mini-lab, set up at home, might be necessary to allow a student to do the required research. For example, the courtship experiment involved making observations of mating tests at dawn. The student researcher had to work at home for this part of the experiment. All other procedures were performed in the high school laboratory.

It is quite probable that a significant period of time will be required before time and procedural "bugs" are resolved. Once these hurdles have been overcome, data-producing "runs" may begin.

9.

DESIGNING AND IMPLEMENTING THE RESEARCH PROJECT

PART II — MATHEMATICS

On Their Own: The Transition to Individual Research

At a certain stage, the student has gotten all he or she needs from the group discussions, and is ready to launch the individual project. This will happen at different times for different students. An exceptional student may be ready to start an individual project on the first day of the term. Others will need to be "pushed out of the nest." Still others will be anxious to work on their own, but will need more work with the rest of the class than they themselves estimate. The teacher will have to be the judge of when to trust a student to go out on his or her own.

Teaching the Art of Conjecture

Starting an individual project can be among the most anxiety-producing parts of writing the research paper. Some students will be beset with fears: How can I think of an original idea? What if I get stuck? What if my problem is too hard or too easy? What if it has been done before? Some see themselves as gambling a lot of time and effort, and much self-esteem, on the success of their project. The first few steps can be the most crucial, and may lead to much anxiety.

The teacher can help to allay this anxiety, and get the students to work better if the selection of a topic is a routine task. That is, the teacher can train students to ask questions about a situation, and perhaps even to assess the difficulty, importance, and elegance of the problem they set. This can be done as part of the class discussion.

The following sequence is one of a number of types of problems which may be used to help stimulate the posing of questions.

Table 1

$$5 \times 5 = 25$$

$$4 \times 6 = 24$$

$$8 \times 8 = 64$$

$$9 \times 7 = 63$$

$$12 \times 12 = 144$$

$$11 \times 13 = 143$$

$$10 \times 10 = 100$$

$$9 \times 11 = 99$$

Students can first be shown the patterns in Table 1. The teacher can get the students to recognize the pattern $(x + 1)(x - 1) = x^2 - 1$. (It is surprising how many students who know this identity in other contexts cannot recognize it here.)

Next, students can be shown Table 2. With a little more prodding, they will be able to see this as $(x + 2)(x - 2) = x^2 - 4$.

Table 2	
$5 \times 5 = 25$	
$3 \times 7 = 21$	$25 - 21 = 4$
$7 \times 7 = 49$	
$5 \times 9 = 45$	$49 - 45 = 4$
$12 \times 12 = 144$	
$10 \times 14 = 140$	$144 - 140 = 4$

Now the teacher can stop asking questions and begin to get the students to ask their own. The lesson can go in several different directions, and at different rates, depending on what the students are curious about. The important thing is to get them curious about this mathematical situation.

Table 3	
$5 \times 5 = 25$	
$2 \times 8 = 16$	$25 - 16 = 9$
$7 \times 7 = 49$	
$4 \times 10 = 40$	$49 - 40 = 9$
$12 \times 12 = 144$	
$9 \times 15 = 135$	$144 - 135 = 9$

Table 4

$$5 \times 5 = 25$$

$$1 \times 9 = 9$$

$$25 - 9 = 16$$

$$7 \times 7 = 49$$

$$3 \times 11 = 33$$

$$49 - 33 = 16$$

$$12 \times 12 = 144$$

$$8 \times 16 = 128$$

$$144 - 128 = 16$$

The students may want to try more arithmetic patterns, such as in Tables 3 and 4. They can derive the algebraic generalizations:

$$(x - 3)(x + 3) = x^2 - 9$$

$$(x - 4)(x + 4) = x^2 - 16$$

$$(x - 5)(x + 5) = x^2 - 25$$

Ultimately, this should lead them to the algebraic conclusion that

$$(x - y)(x + y) = x^2 - y^2.$$

Having seen this, students may begin to ask about what happens to $x^3 - y^3$. Is this factorable in the same way? Trying some numerical examples, perhaps with the aid of calculators, can help them discover the identity:

$$x^3 - y^3 = (x - y)(x^2 + xy + y^2).$$

From here, they may ask about factoring $x^4 - y^4$. One factorization can be obtained by treating the expression as the difference of two squares:

$$x^4 - y^4 = (x^2 - y^2)(x^2 + y^2).$$

If they further simplify the first factor, they will find:

$$x^4 - y^4 = (x - y)(x + y)(x^2 + y^2),$$

so that $(x - y)$ is a factor of $x^4 - y^4$.

Then, having seen that $x - y$ is a factor of $x^2 - y^2$, of $x^3 - y^3$, and of $x^4 - y^4$, students may ask whether $x - y$ is a factor of $x^n - y^n$ for all integers n . This is indeed the case. If students are interested in this phenomenon, they may be motivated to try to find the general form of the other factor. They may be able to find that, quite generally:

$$(x^n - y^n) = (x - y)(x^{n-1} + x^{n-2}y + x^{n-3}y^2 + x^{n-4}y^3 + \dots + x^2y^{n-3} + y^{n-2} + y^{n-1}).$$

(Some students may see the connection between this identity and the formula for the sum of a finite geometric progression. A student who derives this result has a fine intuitive algebraic sense.)

Another tack students may take is to look at the polynomial $x^n + y^n$ for different values of n . This situation is rather more complicated. Working arithmetically, they may find that $x + y$ is a factor of $x^3 + y^3$, of $x^5 + y^5$, of $x^7 + y^7$, and so on, but not of $x^2 + y^2$, $x^4 + y^4$, or $x^6 + y^6$. The discussion can then proceed to the form of the second factor, which is similar to the case of $x^n - y^n$. Or the teacher may use the experience gained to slip in a statement of the factor theorem of higher algebra, which serves to "explain" why the even case differs from the odd.

The students may also get more advanced ideas. The polynomial $x^2 + y^2$ is "prime": it cannot be factored into other polynomials with integer coefficients. Yet if we plug in $x = 4$, $y = 2$, we find that its value is $4^2 + 2^2 = 20$, which is certainly not a prime number. Students may begin to wonder what makes a polynomial prime. Why can't they factor $x^2 + y^2$? Can they factor $x^4 + y^4$? How can one tell by inspection whether a polynomial can be factored?

Other students may launch into number theory. If we plug in values for x and y , the expression $x^2 + y^2$ may or may not represent a prime number. How can we tell if the value of the polynomial will be prime? Can we predict which values for x and y will result in a prime value of $x^2 + y^2$? Can we predict anything else about the resulting value of this expression? Will it be a perfect square? A perfect cube? You and your students will probably think of many other questions to ask.

Throughout all of this, one will find that the further students get in their exploration of the situation, the easier it becomes to get them to generate conjectures. The creative process in mathematics feeds on itself: the more answers one obtains, the more questions one is impelled to ask.

It is important, too, in teaching this sort of lesson, to balance the wild speculation of student conjectures with the sobering influence of cold hard proof, or of whatever level of rigor your students are accustomed to. Conjectures which are built on other conjectures can sometimes be useful, as these can explain the connection between a special case and a more general situation. But students need to be reminded that at some point the party will be over, and they will have to substantiate their conjectures. In fact, some of the conjectures will

certainly turn out to be false, and they will have to modify their original speculations. The relation between conjecture and proof is subtle: neither necessarily precedes the other in the creative process.

Choosing a Topic

Having had this classroom experience, students may begin to be on the lookout for a topic of their own. At this point, it is important to expose them to as many different branches of mathematics as possible. It is important that they choose something which interests them and for which they have acquired sufficient background.

In working through various topics (such as those suggested above), an important aspect of the discussion is getting students to generate their own conjectures about the material covered. Often, the lesson plan may not cover a student's suggested conjecture. It is not important that the answers be given in the lesson: it is more important that the questions get asked. Therefore, one can simply write the student's question on the board, mention that it is indeed worthy of investigation, and go on with the lesson as planned.

Assigning a Topic

There will always be some students who, for one reason or another, will not be able to choose a topic on their own. Some may be afraid to begin their own work. Others may not have found a topic question that interests them. Still others may think that their investigation must "shake the earth" and will be waiting for a sufficiently important idea. For these students, you will need a set of topics to prod them on. A stock of such topics, like a supply of interesting problems, must be built up over the years. The bibliography gives some sources.

One of the more subtle problems of running a research program is learning how to give the right topic to the right student. One may come across a new idea that some student could turn into a fine paper. But if the teacher mentions it to a student who is not very motivated, or has a weak mathematical background, or who is not exceptionally creative, the paper can turn out to be very pedestrian, and the new topic will be wasted for a year or two.

The assessment of a student's creative ability, or motivation to do research, is extremely difficult. Equally difficult is the assessment of the level of a possible topic. If the area is one with which the teacher is familiar, he or she may be able to see just how easy or difficult it will be to arrive at results. But a teacher

may find a student frustrated by not getting anywhere on the new topic which was assigned. It is important to watch for these misjudgments -- which will certainly be made at first -- and see how one can do better next time around.

Some areas of mathematics offer better possibilities for individual research than others. One of these is number theory. Here there are many interesting results lying right on the surface. Students can begin exploring fresh areas of number theory with relatively little background. The field of combinatorics is another one where original results can be gotten at relatively easily. On the other hand, analysis is a very difficult area for students to do original work in. They are often drawn to topics such as curve-sketching or continuous probability distributions. But without the rather powerful tools of calculus, most students will quickly reach a dead end.

Even in these areas, there are exceptions. Some problems in number theory are just too difficult. Some topics in analysis can be reduced to algebra without losing too much content. And of course most areas of mathematics fall in between. It is rarely clear immediately whether a problem is suitable for a particular student.

Some students, on beginning an individual research report, are obsessed with the question of originality. They are constantly asking: "Have you ever heard of this result? Do you know the answer already? Has it been printed?" But these are usually among the least important questions to ask in doing mathematical research. Certainly, a student should be dissuaded from discussing a famous theorem as if no one has ever heard of it. And some of the more usual proofs of such results -- even if the student has thought of it on his or her own -- may look extremely unimpressive when committed to paper. But, by and large, the problem of originality is not one to be unduly emphasized. It has happened many times in mathematics that a useful result has lain buried for years and was rediscovered later on. Indeed, one may not even be able to find out if the idea is original. Mathematical results are notoriously difficult to index. Prior discussion of the topic may turn up long after the paper has been written, and even after it has won recognition.

If students can rediscover an interesting truth, or apply it in a new situation, or give it an original proof, or use it to generate new conjectures, they are doing valid mathematical research.

10.

RECORDING AND INTERPRETING RESULTS



134

139

PART I — SCIENCE

The Log Book

Many people maintain a diary to recall (perhaps even relive) things that have happened to them in the past. The scientist, confronted with a myriad of data evolving from an experiment, likewise wishes to recall the information so that a proper interpretation can be made. Indeed the "reliving" analogy of a "diary" is also true of the science method. The validity or reliability of the experiment will be determined by the repeatability of the results reported in the research paper.

The scientist's diary is the "log book." Everything that is observed is recorded.

Here are a few suggestions about the items that should be maintained in the student's "log."

Student Guidelines for Recording Data

1. Entries should be dated. This is true for observations made daily, weekly, or monthly. It is of value to include the date and also the time of the observations. In addition, you may find that the amount of time spent on the observation is important.
2. Many researchers place a copy of their experimental design or procedure in the log book. This permits them to review and recheck the progress of their experiment quickly.
3. All data should be recorded immediately. Keep a log book and pen at hand. Minute details so vital to understanding the experiment are often "left out" simply because the researcher "forgot" to record them.
4. Most experiments provide sufficient data to reveal the need for more or different experimentation. Questions, concerns, or weaknesses in your design should be recorded as they occur to you. In addition, ideas for other experiments should be noted. These entries will play a vital part in the writing of the "discussion" section of your research paper. Such information also will provide insight in interpreting and understanding the data.
5. Use graphics such as charts, data tables, pictures, or photographs whenever possible. These give a great deal of information in a minimal amount of time and space.

Sample Log Book Entry

7/15/82

2:15 pm - 3:30 pm

Today I prepared culture media for "Drosophila melanogaster." I used prepared media supplied by Carolina Biologicals. Enough media was prepared to fill six culture vials.

At 3:00 pm the culture media was sufficiently set so that I could transfer the adult flies. Two red eye (wild) males were placed in each culture vial. Two virgin, white eye females were likewise placed in each vial.

The anaesthetized flies were observed to awaken within twenty minutes and all appeared healthy.

In the future, I will plan to prepare the media the day before I transfer the flies. This procedure will save me the time used in waiting for the media to "set."

I was not sure that the female flies placed in vial #3 were virgin. Very few flies were available in the stock bottles. Thus, I may have selected some flies that were not suitable for the experiment.

Tomorrow I plan to culture six additional stock bottles so that a greater number of flies will be available.

Student Guidelines for Making Observations

Make Objective Observations

Compare the statements:

Earthworm "A" is much larger than Earthworm "B"; or
"Earthworm "A" is 15 cm long; Earthworm "B" is 10 cm long." The second statement is preferable in a log.

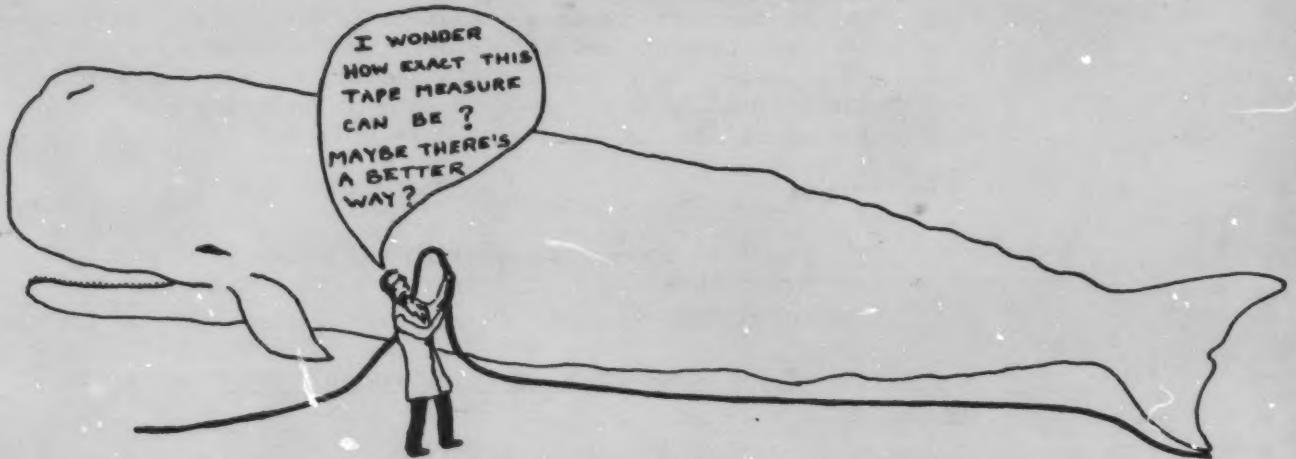
Check the Accuracy of Apparatus

The observations may

be made by using various devices such as: colorimeters, micrometers, analytical balance, pH meters, etc. These observations will be only as accurate as your skill and the accuracy of the instrument.

Describe Precisely the Items Being Measured

A researcher may measure an animal from the tip of its head to the tip of its abdomen. Another researcher may select measurement points from the tip of the head to the tip of its wing. (The wing generally extends beyond the abdomen.) Both measurements are accurate, and both must be noted in the log book. This will permit another scientist, wishing to repeat the experiment, to check your results precisely as you reported them.



Describe the Limits of Degree of Accuracy for Your Measurements

A carpenter's motto that many ascribe to is, "Measure twice--cut once." In much the same spirit the scientist should not rely on a single measurement but on a second or third reading. Some scientists even attempt to obtain a comparative reading using a different method; for example, one might compare the results of a universal indicator with those obtained by a pH meter.

The accuracy of the student's measurements will be tied directly to the sophistication of their instruments. A measurement of 10.52 gms as obtained on a conventional triple beam balance is not as accurate as a measurement of 10.5293 gms which may result from an analytical balance. The type of experiment will determine the extent of accuracy required. The astronomer would be quite satisfied with a one-or two-mile approximation in calculating the distance of a planet in our solar system. However, an engineer concerned with surveying a location for placing support columns for a bridge will require measurements that are considerably more demanding. The cell biologist, measuring in microns (1/1000 of a mm) may require still more sophisticated measurements. Be sure to have your student indicate the degree of accuracy prevalent in the apparatus. The student should not extend the number of places after the decimal beyond the accuracy of the instrument.

Subjective judgments (e.g., degree of sweetness) are at best relative and should be noted as such in the log. A sense of uniformity may be established by having a "panel" standardize the factor being studied. For example:

Sample solution "A" receives a value of (1) for sweetness, solution "B" a value of (2), etc.

Graphics

One of the most convenient ways of recording data, and of bringing together related information is through the use of a variety of visuals. This section describes some of the devices which may be used in both recording and reporting results.

Tables

Suppose the student is measuring the presence of certain chemicals in a number of different bodies of water. The table may appear as follows:

Table 1: Comparison of the Composition of Chemicals in Fresh Water Ponds in Queens

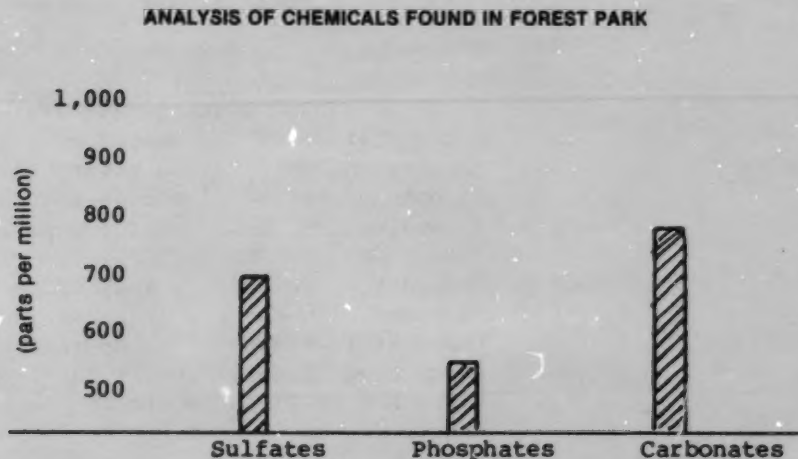
Chemical	Amount of Chemical in PPM (parts per million)		
	Forest Park	Alley Pond	Cunningham
Sulfates	700	875	1,100
Phosphates	550	300	1,250
Carbonates	800	750	1,300

Note the designation of "Table 1" and the corresponding title associated with the table. The information contained in the table is available at a glance and thus allows the researcher to extract data needed for stating the conclusion. Other types of tables include:

- . frequency tables--the number of students getting scores from 0-50, 50-60, 65-75, 75-90, 90-100.
- . time lines
- . scatter diagrams

Graphs

The information contained on a table may be summarized further by using a graph. In the preceding example, the following "bar graph" may be used:

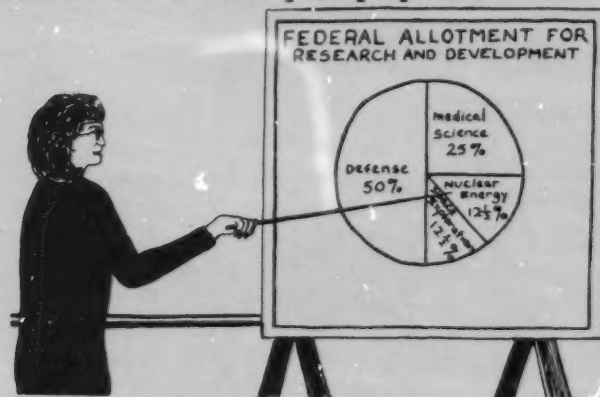


The researcher may present a comparison of the three parks by utilizing different colored bars or keyed overlays.

The line graph is particularly effective in showing how a quantity changes. For instance, the rate of enzyme action (y axis dependent variable) compared to changes in pH (x axis independent variable). In addition, the researcher may compare two or more groups that are subjected to the same condition. For example, the effects of pH (x-axis) on the rate of reactions (y-axis) of Enzyme "A" and Enzyme "B."

Other graph types include:

- a. A pie graph--(sometimes referred to as a circle graph) The circle is considered as representing 100% of the situation being investigated with each portion reflecting a percentage of the whole. Federal and local governments often use this type of graph in reporting percentages of tax monies allocated for a variety of purposes.



b. A picture graph -- The use of symbols such as:

1. varieties of hybrid corn,
2. barrels of oil imported.

Photographs

Those who judge science fair projects look to provide documentation of the research project. Photographs also present the material in a very effective way. We strongly recommend the use of photography as an integral aspect in recording and reporting the experiment.

The cost is relatively low and satisfactory results may be obtained with the simplest camera. Micro- or astrophotography will require more sophisticated material, some of which students may have at home, or which may be available through other departments in the school, e.g., Industrial Arts.

Most commercial film companies are extremely helpful in answering technical questions and in providing specific guidelines for special effects.

The publication, Photography in Your Science Fair Project is available free of charge from Kodak (Rochester, New York 14650). The booklet covers topics ranging from "General Picture-taking Techniques" to "Displaying Your Pictures." Guidelines are provided for using appropriate type film and special lighting techniques.

10.

RECORDING AND INTERPRETING RESULTS

PART II — MATHEMATICS

Introduction to Interpreting Data

After all of the data is carefully collected, tabled and graphed, the researcher is ready to determine if the hypothesis is correct or incorrect. The answer lies in a mass of numbers that have grown out of the well-designed experiment. It is hoped that all the lessons the instructor/advisor tried to teach the neophyte researcher about significant figures, careful measurements, repeatability of procedure and recording data have been learned. If, by chance, these lessons have not been learned, the price will be paid in the form of a poor interpretation due to faulty data gathering.

Defining a Population

The experiments performed by any researcher involve samples or measurements from an ideal population--large or infinite. Since it is impossible to deal with a large or infinite population, the researcher must deal with a small portion or sample population and hope that the sample represents the whole. Examples of populations are: All the students in the world, the number of students involved in a survey of TV viewing habits, the number of Euglena gracilis exposed to ultraviolet light.... There is no absolute number for a population; the experimenter must set up a population according to defined limits

Once the population has been defined, all inferences made in the evaluation of the data from an experiment apply only to the defined sample population. It is important to remember that the sample population must be homogeneous. It would be folly to measure the average height of all of the trees in a forest--oaks, maples, cherry and dwarf pine. Also, a sample population could involve parts of an organism, as well as the entire organism. For example, one might study mass, the height, check cell nuclei of red blood cells, or the number of the villi in the small intestine.

Types of Variables

All physical measurements are statistical in nature. There are no fixed constants, only mean values. For example, the air temperature at any particular time, in any particular place, is an average of the movement of gas molecules in the air.

Statistical analysis of numbers (physical measurements) involves two types of variables: discrete and continuous.

Discrete variables involve countings. The number of male and female fish in a lake, the number of tall or short Pea plants, the number of planaria that survive exposure to

freezing. Discrete variables involve a limited number of values. One can't find 7.6 male fish swimming in a lake. The discrete variables will distribute themselves randomly following a binomial distribution.

Continuous variables are the result of measurements. The diameter of cheek cell nuclei, the mass of planaria, the time it takes to germinate a bean seed, the volume of CO₂ given off by yeast fermenting in a sucrose solution. Continuous variables will distribute themselves randomly following a normal distribution.

Limiting Errors

A project cannot proceed until the researcher has anticipated the potential sources of errors that are to be regulated or limited. Errors can be classified as:

- . major goofs or blunders,
- . systematic errors,
- . random errors.

All three types of errors must be limited if the researcher is going to produce results traceable to the variable being studied.

Major Goofs or Blunders

There is no way to regulate this type of error. Careful work, planning, and checking are the only ways to prevent or limit this situation.

Systematic Errors

This type of error is produced by the instruments used to make measurements and/or the individual making the measurements. For example:

- . The analytical balance might have dirt on the knife edge causing it to stick.
- . The two thermometers used in a procedure have a 5° C difference in readings.
- . Excess humidity has caused the anhydrous chemical reagent to become hydrated.
- . The researcher did not thoroughly clean the glassware before preparing a hay infusion.

Systematic error can be limited by making sure that the same equipment and procedures are used throughout an experiment.

Random Errors

This type of error is due to unpredicted and unknown changes in the experiment or variations in the observer's judgment. The unknown or unpredictable changes might be caused by uncontrollable variations because of instrument design and/or environment. Variations due to observer's

judgment happen when the researcher is estimating the subdivisions beyond the smallest scale division. Random errors can be treated by statistical analysis.

Statistical Analysis of Data

A properly designed experiment is set up so that once the data is collected and organized it is ready for statistical analysis. If goofs and systematic errors have been limited, the last step in the evaluation of the data is ready to be implemented.

Most experiments are designed so that the researcher can state that the results of an experiment are based on a variable and not due to chance. Now the researcher makes a big assumption. The researcher states (mentally) that the treated (variable) population is no different from the untreated (control) population. In other words the null hypothesis is stated.

Before the researcher can continue, a number of mathematical computations must be performed on the data derived from the treated (variable) population and the untreated (control) populations.

The mean for both populations must be determined using the formula

$$\bar{X} = \frac{\sum X_i}{n}$$

Sample Data for Calculating the Mean $\bar{X}$

Data collected from the production of CO_2 by yeast fermenting in a 6% sucrose solution @ 25°C .

	Time (Min.)	ml CO_2
	1	0.90
	2	1.40
	3	1.60
	4	1.80
	5	1.50
	6	1.70
	7	1.50
	8	0.90
	9	1.30
	10	0.80

$$\begin{aligned}\bar{X} &= \frac{\sum X}{n} \\ &= \frac{11.4}{10}\end{aligned}$$

$$\bar{X} = 1.14 \text{ ml/min}$$



Next the researcher must calculate the variance for this mean using the formula:

$$S^2 = \frac{\sum (X_i - \bar{X})^2}{n-1}$$

Time (min.)	ml CO ₂	(X _i - $\bar{X}$)	(X _i - $\bar{X}$) ²
1	0.90	-0.44	0.19
2	1.40	0.06	0.00
3	1.60	0.26	0.07
4	1.80	0.46	0.21
5	1.50	0.16	0.02
6	1.70	0.36	0.13
7	1.50	0.16	0.02
8	0.90	-0.44	0.19
9	1.30	-0.04	0.00
10	0.80	-0.54	0.29

$$S^2 = \frac{1.12}{9} = 0.13$$

Next the standard deviation(s) is calculated

Using the formula: $S = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n-1}}$

From the variance calculations we substitute:

$$S^2 = 0.13$$

$$S = \sqrt{0.13}$$

$$S = \pm 0.37$$

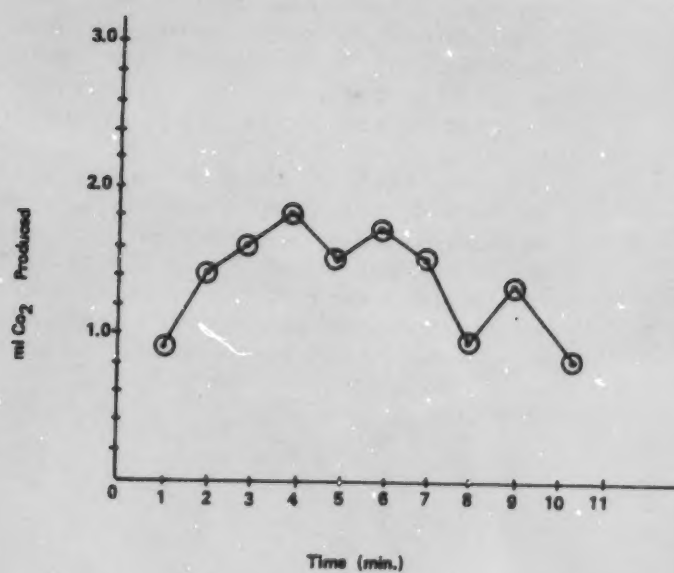
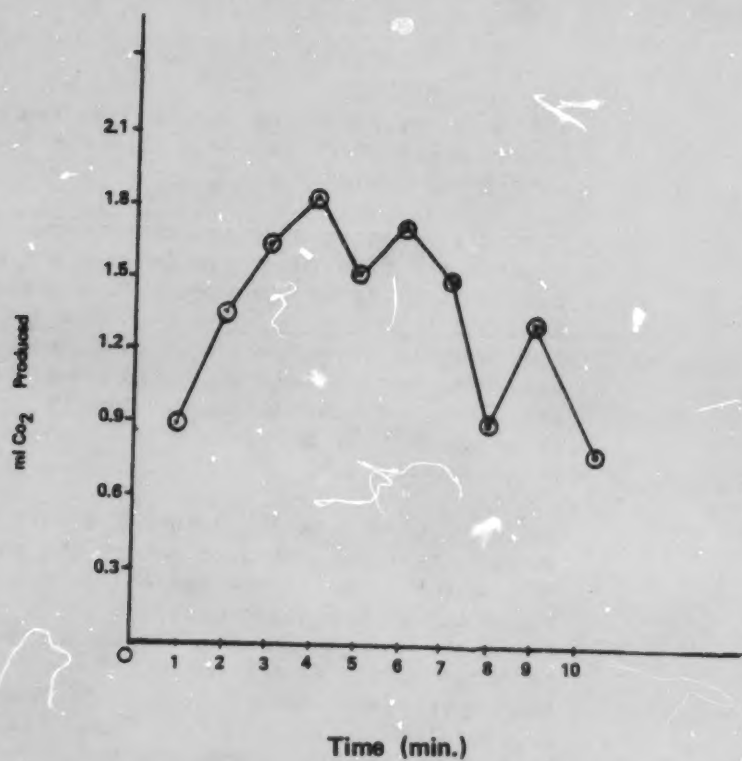
The mean, variance and standard deviations are characteristics of the data obtained from our normal sample population.

The null hypothesis states that there is no difference between the treated (variable) and the control population. It is the object of the research to disprove the null hypothesis: that there is a difference between the two populations and that difference is due to the variable, not to randomness. In most research a 5 per cent level of confidence is commonly used. That is, researchers will accept a 1 in 20 chance of rejecting the null hypothesis.

In order to determine whether the data for the experiment allows the researchers to reject the null hypothesis, the "t" test for continuous variables or the Chi-Square test for discrete variables could be used. These tests are the two most commonly used in biological research. Once "t" on "Chi-Square" are computed, these values are applied to the appropriate distribution of "t" on "Chi-Square" probability tables. If the values fall within the 5 per cent level of confidence, the null hypothesis is rejected. The variable, not chance, caused the observed change. If the results of the "t" or Chi-Square tests come "close" to the 5% level - 5.5% to 6%, the null hypothesis is not rejected, but the researcher might want to go over the procedure to determine the changes required to produce statistically significant results.



The data obtained from the statistical analysis should be reflected on all appropriate graphs where data dealing with means have been plotted. The selection of the type of graph paper, and the values given to the divisions of the x and y axes of the graph will effect the presentation of the data. Graphs 1 and 2 represent two presentations of the data used in the preceding statistical analysis. Note the effects of changing the "y" axis division values and time graph.



147

11.

STATING THE CONCLUSION



Introduction

A well designed experiment will lead the researcher towards a specific set of goals or results. It is to be hoped that Murphy's Law has been controlled and very little has gone wrong, or if it has, that the problem(s) was (were) overcome. In order to make sure that the variable being studied was correctly evaluated, the procedure has been repeated, data gathered, and evaluated. The researcher is now ready for the final step in the experimental process, stating the conclusion(s).

What is a "Conclusion"?

In essence, the researcher in stating the hypothesis, has a fairly good idea of what the conclusion(s) might be. The experiment converts the "mights" into "ares." If the results are completely unexpected, the researcher will have to revise the hypothesis in light of the unexpected results. Regardless of what happens, the research paper ends with a conclusion.

The conclusion is a statement that is the result of the observations and/or data the experiment produced. Simply stated, it is the answer to the hypothesis that was stated at the beginning of the experiment.

Evaluating the Conclusion

The conclusion must be a very specific statement. It must make reference to the controlled condition that was the object of the research and not go beyond the data the research produced. If a researcher was studying the effects of varying phosphate concentrations on the development of root zones in wheat, the conclusion must be limited to the effects of phosphate on wheat root zones. The researcher cannot extrapolate. The conclusion cannot make reference to the fact that "all plants will be affected by varying phosphate concentrations." The data produced are specific for wheat; therefore, the conclusion is specific for wheat.

The researcher may make reference to other published data, and compare his or her results with the other findings. For example, "The results of this paper parallel closely the data obtained using barley (Reine 1977) and corn (Goodman 1942)." A suggestion for future studies might be made at the end of the conclusion.

The researcher must be careful not to conclude that results of a particular research project are not correct because they did not agree with the published literature. For example, if the results of an experiment dealing with the effects of penicillin on the mutation rate of Drosophila melanogaster seem to be contrary to the published literature, it would be incorrect to conclude that the researcher's work is not valid. The researcher should report the findings of the specific experiment and then state that the results disagree with other work published in this area. A possible explanation for the "different results" might be offered.

Quite frequently the results of an experiment do not turn out as expected. In fact, negative results are obtained. It is important to teach neophyte researchers that negative results are just as valid as results that sustain an hypothesis. For example, if the results of the work done on the effects of ultraviolet light on the mutation rate of Paramecium multimicronucleatum demonstrate that the dosages used had no effect on multimicronucleatum, the researcher must publish the work as reflected in the experiment. The negative conclusion has a great deal of significance. It will prevent other researchers from "wasting time" finding out that the doses used in the original Research had no effect on Paramecium multimicronucleatum.

The negative results and conclusion might open up a new area for research. Researchers who read the negative conclusion may begin to ask, "Why is Paramecium multimicronucleatum not affected by the doses of ultraviolet light used in the original research?" The negative conclusion might produce a new series of experiments which:

- a. find the "flaw" in the original research, or
- b. discover a new mechanism for ultraviolet protection that is unique to Paramecium multimicronucleatum.

Care must be taken in stating the cause and effect relationship in an experiment. Event A may not be the cause for situation B.

For example, a student researcher has thyroidectomized a group of animals. The following observations were noted:

1. muscular tremors;
2. lowered body temperature;
3. fluid retention;
4. markedly reduced activity.

It might be reasonable to conclude that the thyroid regulates the homeostatic mechanisms involved in the above

I wonder what
unexpected results
I might have



list of symptoms. Another researcher performs a similar experiment on the organism and observes different masses of tissue within the thyroid masses removed. When these masses are not removed, symptom #1, muscle tremors, do not appear. The parathyroids are discovered..

The preceding example was excerpted from "Invitations" 17-20 of the BSCS teacher's handbook. The teacher should use other examples to demonstrate the serial causes of effects.

The conclusion, as stated earlier, creates "ares" from "mights." Student researchers must be taught how to use and formulate conclusions so that their work is valid and reliable.

12.

DISCUSSION AND IMPLICATIONS FOR FUTURE RESEARCH



Discussion

The researchers are now provided with an opportunity to discuss the results of observations and the conclusions that may be drawn from them.

Problems concerned with the experimental design may be alluded to in this section. For instance, the researcher may note that, "An incubator used for culturing a particular organism had an erratic temperature control. The effects of this vacillation, it is further noted, may have resulted in erroneous data."

In addition to technical problems, unexpected results not necessarily related to the stated problems are discussed. These anomalies are often the basis for future research. For example, Alexander Fleming's astute observation of a fungus contaminate led to the development of antibiotics.

A word of caution: do not permit the students to dwell on errors, negative results, or to maintain an atmosphere of pessimism. The inclinations to downgrade one's result will have a negative spinoff on the many positive aspects of the research.

The "discussions" section also allows the student to contrast the similarities and differences existing in the results with those of earlier researchers.

Suggestions for avoiding certain problems in the experimental design should also be mentioned in this section. These thoughts will be very helpful to researchers desiring to repeat the experiment. For instance, the use of prepared Drosophila media may be as effective, and certainly less time-consuming, than researcher-prepared Drosophila media.

Implications for Future Research

Scientists concur with a basic premise in experimental procedure--that a well-designed experiment often results in more questions to be answered than solutions actually obtained.

It is of importance for the researcher to note the next logical series of experiments that should be conducted in the research. This statement, coupled with a thorough discussion of the significance of the findings, provides

the framework for future research. For example, a researcher may express the desire to use a pH meter as opposed to various universal dyes in order to obtain greater accuracy. The results obtained using the pH meter may yield data that could result in a conclusion that is different from that of the original research. Unexpected results, as indicated earlier, provide a myriad of possibilities for additional research.

The teacher should instruct the students to continue reading literature related to their research. Often a thought will evolve, based on a particular publication, that may augur additional research or a modification of an existing experiment.

Another example for further research may be the selection of a different variable. For example, the student examining the effects of a certain chemical on a life process of an organism may redesign the experiment to investigate the effects of temperature on the same life process.

The listings of "variables" are almost limitless, as is the search for a valid and reliable conclusion. The pathway of science investigation opens doors of inquiry. It never seals the search for knowledge.

Teacher's Notes



13.

PRESENTING THE ORAL REPORT



PART I — SCIENCE

Introduction

In addition to writing the research paper, the student may be expected to present an oral report of the findings. The New York City Science Fairs, the Otto-Burgdorf Congress, the St. Johns Symposia and various mathematics fairs, as well as "finalists" in the Westinghouse Science Talent Search, all have a judging modality that requires an oral presentation.

The guidelines for presenting the oral report vary from contest to contest. For instance, The New York City Science Fairs permit a three-minute summary statement by the participant - followed by a two to three minute question and answer period. The finalists in the Otto-Burgdorf Congress present a 45-60 minute oral report. The teacher is advised to review the particulars in various contests and to plan accordingly. In addition to contests and forums, the oral report is an excellent evaluation tool for the classroom. A sample of the evaluation sheet used at Grover Cleveland High School follows. Modifications are strongly advised to meet the needs of varying school programs.

Teacher's Notes



Sample Oral Report Evaluation Form

Student's

Name _____

Research Project: _____

Suggestions to the Student

Tailor the report for the audience. Explain all the technical terms and techniques which are in your report.

Comprehend your research paper. Don't read it. Outline the topics you want to cover on index cards.

Rehearse exactly what is to be said. You should not appear before an audience and say, "I know what I mean, but I cannot express it."

The report should be presented in an organized manner. Your introduction should include a clear statement of the problem. Tell what you did and support your statements with evidence and data.

Use visual aids: charts, models, graphs, pictures, apparatus; in short, sell your product.

Time your report. If you get bogged down with detail, the major concepts will not be developed.

Acknowledge assistance that you obtained in the research.

Make reference to faults in the experimental design.

Have respect for your audience and do not feel obligated to justify every criticism made about your report.

Questions should be answered honestly and sincerely.

Practice your oral presentation out loud several times in front of a mirror or with a cassette recorder.

Rating Scale

	<u>Value</u>	<u>Earned</u>
A. Clarity of presentation	20	_____
B. Quality of Research	20	_____
C. Timing	10	_____
D. Use of Visual Aids	10	_____
E. Knowledge of Subject	20	_____
F. Prospects for Future Research	20	_____

Comments

EVALUATOR'S SIGNATURE

The evaluator (teacher or panel) will rate the student and then arrange for an individual counseling session to discuss the grade. If two or more evaluators are present, a weighted average is provided.

Types of Oral Presentations

The oral presentation may assume a number of forms:

- . classroom presentation
- . science fair competition
- . lecture forum - paper presentation
- . panel forum - informal discussion session for the benefit of the audience
- . symposium forum - each participant on the panel presents a formal address, before the discussion is pursued
- . debate forum - involves a controversial problem for which two or more opposing views may be discussed.

Regardless of the format, a number of guidelines should be followed:

The oral presentation should provide the audience with the most essential features of the research in a manner that is designed to be understood at the first hearing. Thus, a clear, concise, logical format must be available.

The student must be provided with practice in this skill. Public speaking, as with writing, is a skill that must be acquired, and may be acquired only through practice. The informal "classroom" presentation is an excellent mechanism to provide a platform for practicing the report

The core of the presentation must be concerned with: the problem statement; related research; significance of the investigation; and a brief description of how the data were collected and interpreted.

The technical vocabulary used in the presentation should be geared to the audience. A presentation on "computer technology" will be different for an audience of engineers as opposed to a group of interested, albeit non-mathematically versed citizens. In either case "simplicity" and conciseness are essential for a successful presentation.

The use of visual aids will enhance the effectiveness of the oral presentation. The student must be guided in the design of visuals that are large enough to be seen by the entire audience. Obviously, the visuals (charts, slides, pictures, models, and apparatus) should be accurate and be designed to promote both audience understanding and interest.

The Question and Answer Period

Most oral presentations include a question-and-answer period. This part of the presentation will take on different forms, depending on the nature of the audience.

If the report is given in the research class itself, the audience will probably know somewhat less about the topic than the student presenting. Hence they will know less about the direction in which their questions lead. Some questions will be too easy. The speaker must answer these with respect. Ignorance of a specific topic implies nothing about one's overall ability. Other questions will be too difficult, and the roles will be reversed. The student presenting will need to be able to say something intelligent. Sometimes a conjecture is appropriate. Sometimes the question can be related to one which the student knows how to answer. And sometimes there is a need for a frank admission that the question goes too far afield, and discussion should be tabled.

The teacher plays an important role in question-and-answer sessions in the class. Often, students cannot think of appropriate questions, and their silence can be received by the speaker as disapproval. At these points, the teacher should step in with a question or two. This may give the class an idea for further inquiries.

Sometimes a question period can be followed by further class discussion, led by the teacher. These discussions can be used to reinforce a spirit of scientific inquiry in the classroom. If students are not able to think of questions, the teacher can elicit questions from them. If the speaker has trouble handling the questions, the teacher can show by example how this is done. The teacher can invite questions and show how to handle difficult ones. This can be done without implying criticism of the speaker.

The aim of such a discussion (and, in fact, of the whole questioning process) is to get students to enter into the topic together, using the student-expert as a resource. Once the class has acquired this skill, the teacher can play a more passive role in these sessions.

13.

PRESENTING THE ORAL REPORT

PART II — MATHEMATICS

The Oral Report in Mathematics

The student presentation of a project in mathematics differs from such a presentation in the sciences in some important ways. A mathematical presentation should not proceed chronologically. Instead, the most important results should be stated first, with more and more detail added later on. It is helpful to think of the model of a newspaper article. The headline screams out the final result. The first paragraph sketches the scene. Succeeding paragraphs fill in more and more color, more and more detail, until a complete picture emerges.

In just this way, the student presentation of a mathematics topic should first give an overview of what topic was investigated and what was achieved. Next, connections with other research can be made clear. After this, the student can show some of the main results in detail. If non-standard terminology is used, it should be explained. A clear statement of the result in intuitive terms is always more impressive than a more technical statement -- but the student should be prepared to give the full statement if this is required.

There is usually not enough time in an oral presentation to give the details of a proof. But the nature of the proof can be outlined. Was it done directly? Did it involve induction? Is it similar to a type of argument occurring in other areas? Most important, is there some clue as to the motivation behind the argument? Some mention of clever attacks which unfortunately failed also can have a place.

Finally, the student should include a discussion of what has turned up since the paper was written, or some speculation as to how further research might proceed. A shrewd conjecture, even if not proven, makes a good ending.

14.

COMPETING AT SCIENCE AND MATHEMATICS FAIRS



PART I — TYPES OF COMPETITIONS

Types of Mathematics and Science Competitions

When a researcher has completed a mathematics or science project or experiment, the paper that is written is published in one of the many journals or professional magazines that service a particular area of concentration. A high school researcher has little or no chance of publication, but the work that students have produced should be recognized. The avenues for recognition, on a local or national level, are the science competitions. These competitions are the science fairs, mathematics fairs and contests, SEER, Westinghouse National Science Talent Search, Otto Burgdorf Conference, etc.

Each of these competitions performs a specific function. In general all competitions provide the student researcher with an avenue for recognition, but each provides this recognition in a different way.

Westinghouse — NSTS

This competition, open to seniors, is one of the most prestigious in the country. The competition selects 300 semifinalists (Honors Group) and 40 finalists, selected from the 300 semifinalists. The finalists attend a finalists competition, held in Washington, D.C. to select the ten best papers. Each of the finalists receives cash prizes. These grants help defray the cost of college tuitions. Entry in the Westinghouse Competition, initially, involves the completion of the research paper and the filling out of a data sheet application. Specific details for the research papers and the acquisition of data sheet applications may be obtained by writing Science Service, 1719 N. Street, N.W., Washington, D.C. 20036.

Student evaluation for the Westinghouse Competition involves the research paper and the answers to the questions on the data sheet. The student and the advisor answer a series of questions that help the Science Service gain insights into the student's background, personality, and level of achievement on standardized tests. The research class teacher-advisor should have students prepare their answers to the data sheet questions in October of the senior year. A number of revisions will have to be made until each student has answered the questions which will provide the Science Service with the student's best profile. The advisor must have completed all data sheets by the first week in November. This will provide time for a thorough "think through" of each question the advisor must complete.

Final drafts of papers and completed data sheets must arrive at Science Service by December 15.

Science and Math Fairs

The New York City Board of Education in conjunction with the Daily News, The New York Academy of Science, and American Institute of Science sponsor a series of science fairs. The borough-wide competitions involve winners from the following groups: 7-8th grade, 9th grade, and 10-12th grade winners. The 10-12th grade students enter by specific discipline. The borough finalists are selected from the 9th and 10-12th grade winners. These students compete in a citywide science fair. The 9th grade winners at the citywide fair receive a book award. The city finalists in the 10-12th grade category go on to compete in the International Science Fair sponsored by the Science Service.

Since each school is allowed a limited number of entrants, the selection of students for participation in the borough Science Fairs should be made at a school science fair or by some other screening device. Applications, guidelines used in project classification and eligibility, and publicity posters are sent to each school from the Science Unit, 131 Livingston Street, Brooklyn, New York.

The format for science fair competition differs greatly from that used by the Westinghouse N.S.T.S. Students are judged based on an oral presentation -- three to five minutes long -- a brief written description of the project (abstract) and an exhibit of the project work. Each project is evaluated with reference to the quality of the concept, method, technique, format, and interview. These guidelines are set down by the American Institute of Science, Syosset, N.Y. The judges are instructed to consider each of the following items in the five categories:

CONCEPT--creativity and originality of exhibitor, timeliness, significance, grasp;

METHOD--clarity of problem, planning, use of scientific procedure, evident results;

TECHNIQUE--workmanship, appropriateness of materials, safety precautions, records kept;

FORMAT--appearance of exhibit, lettering, spelling, organization, dramatic value, size;

INTERVIEW--preparation, knowledge of principles, self-evaluation, integrity, attitude, responsiveness to questions, resourcefulness, courtesy.

Since the quality of the presentation rather than an in depth study of the project is the primary factor in the evaluation of the project work, it is very important that the advisors stress many of the concepts outlined later in this chapter. Many outstanding research projects have failed to gain recognition at the science fairs because the students did not understand the criteria used for judging their work.

SEER

Since the energy crisis of the early seventies the SEER competition has grown significantly. Indeed, this national competition was an out-growth of the energy crisis. SEER provides students with an opportunity to channel their efforts towards developing projects and techniques that will promote better use of current energy sources, development of new energy sources, and adaption of established ideas to new problems.

Publicity for the SEER competition is sent to every junior high school and high school. The competition is sponsored by many private corporations involved in the production, distribution, and use of energy. The competition areas involve work on projects dealing with such energy sources as solar, nuclear, and fossil fuel.

The projects are judged on the basis of displays prepared by the student researchers. The application requires the student to prepare an abstract of the project work that will accompany the display. In the future the judging procedure might involve a student interview phase.

Otto Burgdorf Science Congress

The Junior Academy of Sciences and the New York City Biology Teachers Association sponsor this Congress. Student research projects papers are submitted to the Junior Academy. The papers are evaluated by a committee made up of student members of the Junior Academy and teachers from New York City Biology Teachers Association. The Congress is held in May of each year. Students who have participated in this competition have expressed a great sense of awe and self confidence as a result of presenting their work before an audience of hundreds of their peers. After the winners are selected, workshops are set up to assist students in getting ready to present their papers at the Congress.

Other Science/Math Competitions

There are many other local and national competitions that students can enter. NASA has sponsored science competitions to stimulate students to do project work in designing experiments that eventually ended up on Viking, Skylab, and Space Shuttle flights. The advisors of the science or mathematics research class must keep their antennae tuned to the publicity that advertises these and similar competitions.

14.

COMPETING AT SCIENCE AND MATHEMATICS FAIRS

PART II — SCIENCE

166

181

Preparing for Science Competitions

The previous section, provided an overview of the vast variety of science/mathematics fair competitions that are available to students. Each program engenders guidelines that are unique to the sponsor's goals. Thus the participants will be well advised to review the instructions carefully and not assume that because a contest looks similar to one that they may have participated in that the instructions are identical.

The Research Paper

As indicated earlier in this publication, the research paper represents the documentation supporting and reporting the student's experiment. With minor exceptions most science/mathematics competitions require submitting a research paper. Variations in length, documentation, graphics, and abstracts are listed in the set of instructions. Since these guidelines are subject to periodic change, the advisor should review these carefully with the participants each time they compete.

Displaying the Project

Most school, boroughwide and citywide science fairs require the participants to display their projects and to make oral presentations to a team of judges. The actual space allotted for the project display and the approximate length of time provided for presenting the project will vary from contest to contest. The New York City Science Fairs, for instance, allow the student three minutes for the oral presentation followed by a two-minute question and answer period. The display board at this fair may not exceed the following dimensions: 4 feet long, 6 feet high and 4 feet deep..

A number of strategies can be used to assist the student in preparing and presenting the project:

The Display Board

Construction of the display board will be one of the most important tasks undertaken by the students. A board that is poorly supported, has sloppy lettering, or is illogical and uninteresting, will present a very poor first impression on the judging team. Project construction and display generally account for only 5-10 per cent of the total score. However, the effect of making a good project look bad or vice versa must be considered.

a. Lettering:

Lettering may be done freehand, or with the use of commercially available "press-ons" or stencils. Be sure that the students' spelling is correct.

b. Graphics:

The use of pictures, graphs, drawings and other visuals "dress-up" the display board and provide judges and participants with a positive impression that the student is really concerned about the presentation. The spin-off may be that judges are disposed to believe that similar care was provided in the implementation of the experiment.

A Model Display Board

← 2 1/2 feet → ← 3 feet → ← 2 1/2 feet →		
<u>OBSERVATIONS</u> photos drawings charts graphs other visuals: computer printouts	<u>TITLE</u> <u>HYPOTHESIS</u> <u>DESIGN</u> <u>MATERIALS</u>	<u>CONCLUSIONS</u> <u>FUTURE RESEARCH</u>

(4-foot display area)

- (1) Construction material: pegboard; masonite; plywood; paneling; heavy pressboard; hinges.
- (2) Lettering: cardboard pressed letters, stencils, printing black ink on light background, oaktag on board.

In labeling the display items keep in mind the rules of the fair. For example, the New York City Science Fairs do not permit the display to identify either the student or the school. Thus reference to both must be deleted or "masked."

The Oral Presentation

The restriction of time placed upon the student for the oral presentation is stringently followed and requires careful preparation. Within the time allotted, the student must present the problem, the experimental design and the results. In addition, he or she has to provide the judges with an appreciation of thoroughness, technical skill, and understandings acquired (including the mastery of subject content), and the implications of the research. Specific guidelines for the New York City science fairs were presented earlier in this chapter.

At the Fair

Encourage the students to arrive early and to set up their display in the assigned area. Have them call attention to specific problems (i.e., need for an electric outlet, additional space requirement, etc.,) to the proctors or other science fair officials. Apparatus should be tested and placed on display in accordance with a previously prepared outline. Time permitting, the student may wish to review or practice the presentation prior to the actual judging.

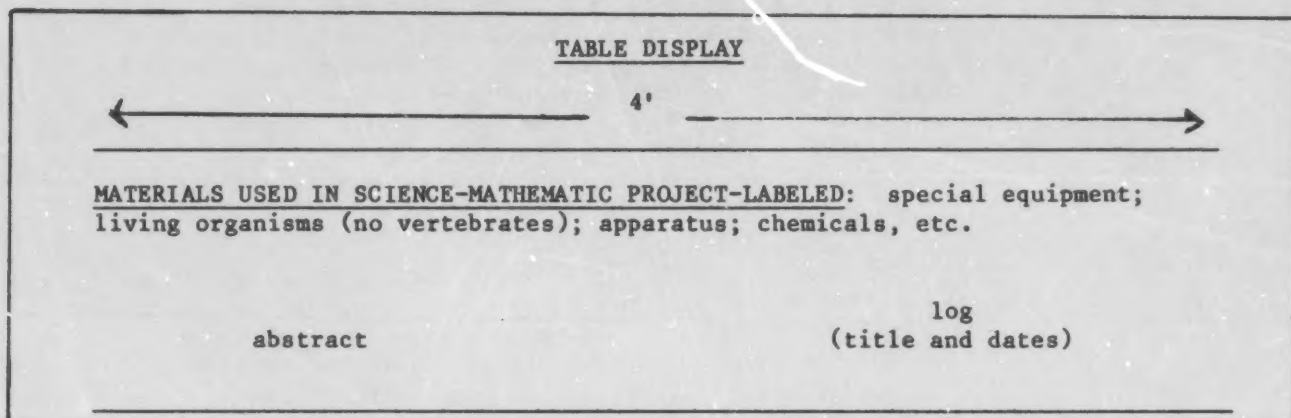
Participants may expect a two-to three-hour wait for the judging to be complete. Many fair sponsors, cognizant of this wait, will permit the students to bring some food or drink to the fair. (Check the local regulations in this regard.)

Student dress, although a criterion that is not consciously judged, may influence the judges' final score. The student who presents him or herself in a socially acceptable manner provides an aura of confidence that will enhance the presentation of the project. Advise the student to answer questions posed by the judges in an honest and sincere manner. The student is not expected to know all of the answers, and should not hesitate to admit lack of knowledge or understanding. The student should be advised to accept criticism gracefully and to avoid establishing an adversary relationship with the judges.

Finally, students need an expression of their teacher's pleasure and pride in the work they have done. This support is particularly important if the student's project has not been given an award.

The science/mathematics display board should provide a coherent, concise representation of the experiment. The effectiveness of the student's oral presentation will, to a large extent, be determined by the display board format.

The space immediately in front of the board should effectively assist the presentation and supplement the material presented on the display board. A suggested format is shown below.



- (1) Abstract - 75-100 words, double-spaced, typed (50 copies).
- (2) Log - inclusive dates; all observations and pertinent notations.
- (3) Labels - all items on display must be accurately labeled and identified.

Note the inclusion of an abstract and a log accompanying the display. Judging teams will want to refresh their memories by reviewing the abstract at the end of the judging session. Likewise, visitors to the fair will find a copy of the abstract to be most helpful in recalling the projects they have seen.

The log should be the actual diary used in the experiment. Caution students not to rewrite the entries lest the judges receive the impression that a log was not maintained but simply put together at the last moment for the science fair.

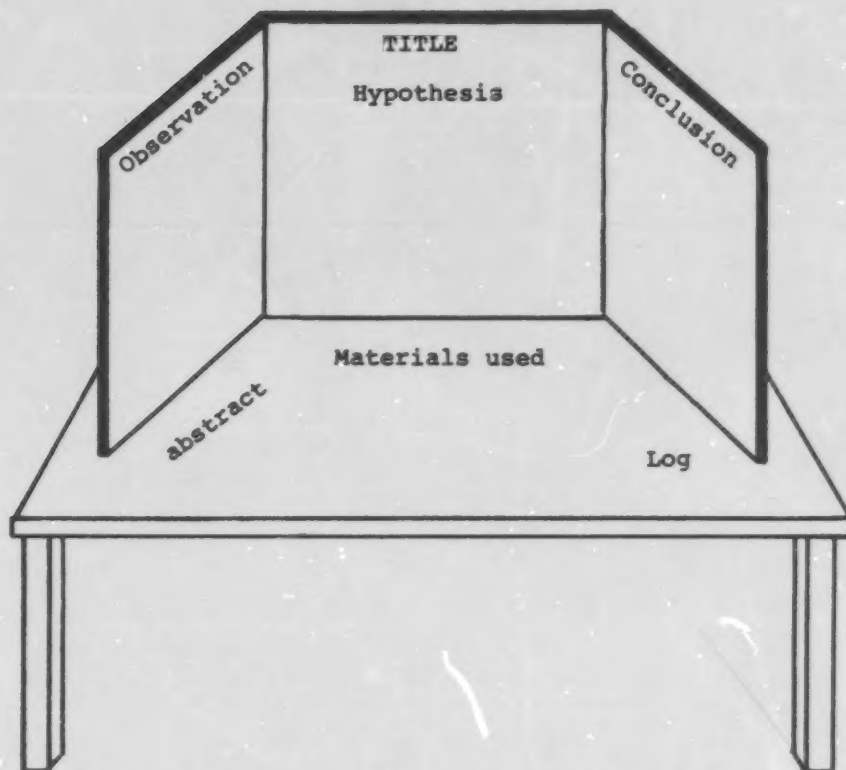
Words of Caution

Never leave the fair project display unattended. Many fairs attract thousands of visitors. The potential for an expensive piece of equipment or an attractive display item to be stolen always exists. Arrangements should be made to have students watch each other's display so that they all have an opportunity to view and to learn from the other projects.

Some useful references:

Harvey Goodman, "Injecting Objectivity into Science Fair Judging" - The Science Teacher, Volume 48, Number 2 February 1981. (Deals with specific problems concerned with the judging procedure.)

Harvey Goodman, "At the Science Fair" - The Science Teacher, Volume 42, Number 9, November 1975. (Summarizes many of the preceding chapters and planning for the fair).



How a model display table and board may be arranged.

14.

COMPETING AT SCIENCE AND MATHEMATICS FAIRS

PART III — MATHEMATICS

Types of Mathematics Competitions

The Greater Metropolitan Mathematics Fair is the chief event devoted entirely to student research in mathematics.

Students compete on four different levels, depending on the level of the mathematics course they are currently taking.

Students currently in ninth- or tenth-year classes submit their papers early in January to be screened by a panel of judges. If the paper is accepted, the student is then invited to participate in a first round of competition. On a Sunday in March, these students give a fifteen-minute presentation to a panel of three or four judges. A question period ensues, and the judges pick the best papers to be presented in a second round of competition. This round is held two weeks later, and the winners receive gold, silver, and bronze medals.

Students competing on eleventh and twelfth year levels follow a similar procedure, except that their papers are not screened in advance. Every student on this level gets a chance to present his or her work in the first round.

There are a number of contests which students can enter in both mathematics and the sciences. These include:

- the Otto P. Burgdorf Science Congress
- the St. John's University Science Symposium
- the Westinghouse Science Talent Search Program
- the New York City Science Fair (which allows for entries in mathematics as well)

Students should be reminded that success in these competitions depends on the depth of their research, but that an element of chance pervades the contests. By entering more than one contest, the chance that a good piece of research will be overlooked can be minimized. Although the objective criteria for judging the various contests are similar, each panel of judges has its own personality, its own fields of interest, and its own basis on which to compare the papers. A paper which is overlooked in one competition may receive accolades in another.

At the Math Fair

The presentation of a mathematics research paper should include a display or some other visual aid, as well as a talk by the student.

The display is intended first to attract the eye. Once this is accomplished, the viewer should be able to tell

quickly what field the project is in, what work the student has done, and what results have been achieved.

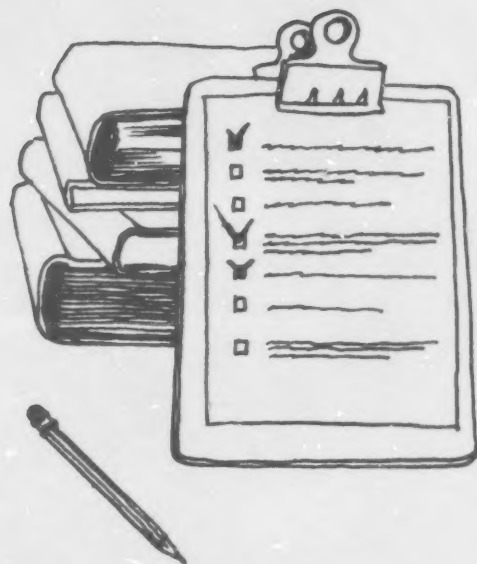
If the paper includes any diagrams, the more dramatic-looking ones should be enlarged and displayed. If there are no diagrams, new ones may have to be invented for display purposes. If this cannot be done, perhaps some of the more important results can be concisely displayed using appropriate symbols. The form of some competitions makes a display inappropriate. In the mathematics fair, for example, the presentation is given at a chalkboard with the judges seated in the audience. If there is no display, the talk must include more visual aids. Chalkboard diagrams, charts, or overhead projector transparencies should be ready.

If none of these aids is available, the display should be designed to serve the same purpose. The judges are more likely to remember something they have seen than something they have heard.

Most judges will ask questions of the student. Students should know that they are often genuinely interested, and are not merely "quizzing" the student. If the student is also interested in his or her project--and most students will be--there can be a favorable rapport established between the student and the judge. More important, a relaxed attitude on the student's part will make the presentation a more enjoyable experience, whether or not the student comes home with a prize.

15.

EVALUATING SCIENCE AND MATH PROJECTS



Evaluating Science Projects

All of us recognize the need for evaluating our students and providing them with a fair grade that is reflective of their work.

In the article, "Injecting Objectivity into Science Fair Judging," Goodman states: "Many science fair evaluators have suffered at one time or another from the nagging feeling that judging is at best subjective and at worst borders on the arbitrary." * This article elaborates upon the problems concerned with evaluating science projects, and, suggests a number of objective criteria that may be used to help quantify the procedure.

Adapting some of these criteria will be of value to the teacher in evaluating the student.

The categories are presented in the form of a checklist. It is suggested that the instructor modify the criteria and provide a definite point value for each item. Furthermore, it is advisable that this listing be provided to the student at the beginning of the program. Each category should be explained in detail and include an understanding of the scoring procedure.

* Goodman, Harvey, "Injecting Objectivity into Science for Judging" The Science Teacher, Volume 48, Number 2, February 1981.

Research Evaluation Form

1. Some evaluators prefer to evaluate each category in accordance with a rating scale. For instance:

5=Excellent

3=Satisfactory

1=Poor

4=Good

2=Fair

0=Does not apply

If twenty categories are selected, with a maximum point value of "5" for each area, then a numerical grade up to a maximum of 100 percent can be obtained.

2. In selecting the items to be used for your evaluation, it is advisable to include categories reflective of the following major areas:

a. selection of the problem to be investigated;

b. literature research;

c. the experimental design;

d. collection and interpretation of data.

Categories for the Evaluation Form

1. The problem was clearly stated.
2. The problem was of current concern.
3. The literature research was appropriate for the investigation.
4. The literature research contained both current and dated references.
5. The literature research reflected the use of journals, texts, original papers and other media.
6. The hypothesis was a logical statement that related to the literature research.
7. The methods used in the experimental design were appropriately selected to permit the acquisition of data for the project.
8. The materials used in the experimental design provided accurate data.
9. The description of the experimental design was precisely written to permit other researchers to duplicate the experiment.
10. The log book had entries that were entered daily and were accurate and concise.
11. Observations were recorded daily, and limitations regarding the accuracy of the observations noted.
12. Tables, graphs, illustrations, or photos were used to record the data.
13. Interpretation of the data reflected the actual observations made by the researcher.
14. Statistics and/or computer analysis were used in the interpretation of data.
15. The conclusion corresponded to the observations and related to the hypothesis.
16. The discussions section fully described specific problems encountered in the experiment and how these anomalies may have influenced the results.
17. The bibliography and reference sections contained literature that was used in the research paper and not simply listed.
18. The discussion section suggested further research problems that resulted from the experiment.
19. The experiment was conducted a number of times so that the data could be verified.
20. The oral presentation was clear, concise, and accurate.
21. The oral presentation made good use of visual aids.
22. The research paper was properly footnoted and provided acknowledgements for support and assistance in project development and implementation.
23. The student improvised equipment used in the experimental design.
24. The science fair display board presented the project effectively.
25. The experimenters initiated their own research project.
26. The student used outside agencies effectively.
27. The student used acceptable laboratory procedures.
28. The written report was neatly typed, illustrated, and in acceptable form.
29. The student used objective measurements and stated the limits of accuracy.
30. The student demonstrated a sense of responsibility and cooperation with peers.

Summary

The instructor will have to select those categories that are related to the unique conditions existing in the school. The instructor may find that a more concise, simplified listing, which combines a number of categories is adequate. On the other hand, some instructors may wish to elaborate on specific categories and to expand upon them in greater detail. Finally, some will consider using a simplified evaluation tool for beginning classes, and a more comprehensive device for their advanced program. In either case the teacher should not feel compelled to stay with any particular design. As with the experimental procedure being pursued by the student, the evaluative tool selected by the teacher will require constant revision.

Evaluation of Mathematics Projects

On the whole, it is much more difficult to find objective criteria for judgment in mathematics than in the sciences. Projects in mathematics call upon a wide range of methods of proof or of exposition. Although some methods are clearly inappropriate, there is sufficient latitude for individual opinion in judging.

Different judges will have different ideas about the level of achievement of a project. But it is important for them to agree on what qualities they are looking for in the paper. Listed below are some suggestions about what to look for in judging a mathematics project. Which of these criteria are to be applied, and how they should be applied, will depend on the nature of the work being judged and on the experience of the judges.

1. Are the results clearly stated?

Even within a given level of rigor, the statement of a theorem can be clear and elegant or overly complicated and "baroque."

2. Is motivation given for proofs or conjectures?

An oral presentation provides a good opportunity to explore the often overlooked question of motivation. Also, a student's motivation for a proof frequently gives a better indication of the originality of the work than the proof itself. The same result calls forth different modes of understanding in different individuals.

3. Is conjecture clearly separated from proof?

Students sometimes feel that a restatement of a theorem constitutes a proof. Other times, they may think that relating one conjecture to another proves both. The relationship of one conjecture to another is a valid topic of mathematical discussion, but the logical status of a conjecture should never be in doubt.

4. What was the level of mathematical rigor in the discussion?

Different levels of rigor can be expected from students with different amounts of experience.

5. Are proofs correct?

This is sometimes seen as the ultimate criterion in mathematics. But judges should realize that students, like musicians, can be "great even in their mistakes."

6. Were conjectures made and substantiated where proofs failed?

Conjectures should not be wild guesses. They should be summaries of patterns which appear to hold.

7. Does the project show the student's own effort?

This is the most difficult criterion to apply. The judges tend to be impressed by any result with which they may not happen to be familiar. But a result which is new to one person may appear old and worn to another. A judgment of originality depends heavily on the varying backgrounds of the judges.

In judging for originality, the focus should be on originality of approach rather than a result. An effort should be made to determine how much of the work was borrowed from other sources, how much was integrated from these sources into the student's own approach, and how much was invented by the student on his or her own.

8. Was the significance of the project made clear?

Some projects are related to classical results in mathematics. Others can be applied to solve problems in non-mathematical areas. The student can discover these connections through background reading.

9. Was the oral presentation made efficiently and thoroughly?

A complete and succinct oral presentation requires much thought and preparation. It shows a good understanding of the work which has been done.

10. Were helpful visual aids provided?

These should be judged by quality rather than quantity.

16.

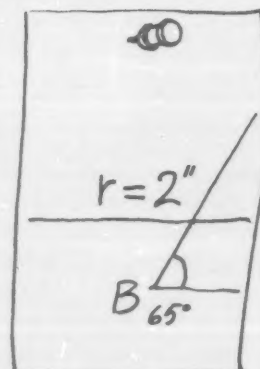
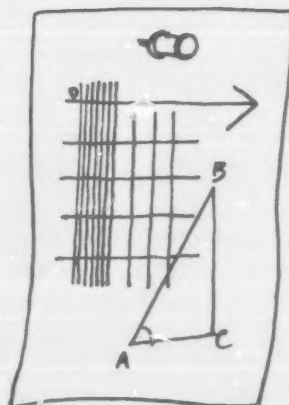
SAMPLE SCIENCE AND MATHEMATICS RESEARCH PROJECTS

○

$$\bar{X} = \frac{\sum X}{n}$$

$$= \frac{11.4}{10}$$

$$\bar{X} = 1.14 \text{ ml/min}$$



Sample Research Problems in Biology

Title: The Effects of Ultraviolet Radiation on *Euglena Gracilis*

BACKGROUND INFORMATION

Observed changes in *Euglena* exposed to ultraviolet (UV) light. Include a "bleaching" effect on the cell which may be transmitted to succeeding generations (Lyman, H., "Studies of Chloroplast Development in *Euglena*," Biochem. Biophys. Acta, 50:301, 1961.)

SUGGESTED DESIGN

A commercially available germicidal lamp, such as the General Electric G15 T8, may be used as a source of UV irradiation. One procedure should vary exposure time (20 seconds to 3 minutes) at a fixed distance (7.5 cm). Another possible design may fix the exposure time to 30 seconds but vary the distance (2.0 cm to 7.5 cm). The student may then observe changes and reinoculate organisms to determine permanent genetic change.

Title: Determining the Presence of Antibiotics in Germinating Tomato Plant Seeds

BACKGROUND INFORMATION

Antibiotics are produced in abundant quantity and variety by microorganisms. The actinomycetes have been the most explored group of organisms and have yielded most of the commercially available antibiotics. In 1959, Maruzella and Freundlich reported the presence of a compound named "Tomatine" in tomato leaves, which is particularly effective against fungus infections. (Maruzella, J.C., and M. Freundlich, 1959 "Antimicrobial Substances from Seeds," J. Am. Pharm. Assoc. Sci. ed. 48: 356-58). Most research on higher plants has been concerned with leaves, stem, and root potential for antibiotic production. Relatively little effort has been devoted to the possibility of antibiotic production in seeds.

SUGGESTED EXPERIMENTAL DESIGN

An intensive study may be conducted to determine the antimicrobial potential and effectiveness of a single type of tomato plant seed grown on a number of each culture dishes each containing a different species of bacteria.

A second possibility would be to screen different seeds on a single microbe.

A Sample Research Problem in Chemistry

Title: Determining the Effect of Temperature on Solubility

BACKGROUND INFORMATION

"The change of solubility with temperature is closely related to the heat of solution of the substance.... the process may be represented as follows: Solute + solvent ----- saturated solution + heat." (Sienko and Plane; Chemistry, McGraw Hill Book Company, 1976, p. 212).

SUGGESTED DESIGN

Select a(n) appropriate solute(s) that readily dissolve in water. For instance, potassium chloride (KCl) may be chosen. Calculate the solubility of a known quantity of KCl in 100 ml of water at room temperature and compare with the solubility of the substance for a wide range of temperatures. An alternate approach may be to select a solute that dissolves in a number of solvents (water, alcohol, acids, bases) and to compare the relative effectiveness of these solvents as a result of temperature change.

A Sample Research Problem in Physics

Title: A Determination of Factors that Influence the Magnitude and Direction of Induced Currents

BACKGROUND INFORMATION

Michael Faraday in England and Joseph Henry in the United States, working independently, investigated the use of magnets in the generation of electricity. They determined (in the mid 1800s) that a current can be induced across a conductor that is moving through a magnetic field. (Stollbert and Hill, Physics, Houghton Mifflin, 1980, p. 306.) An understanding of various physical, chemical and environmental factors is vital in the development of new and better conductors.

SUGGESTED EXPERIMENTAL DESIGN

A relatively simple compact coil may be designed by using various types of metal wire (copper, aluminum). A galvanometer may be used to measure the induced current resulting from a magnet thrust through the coil. Variations of the experiment involve the use of different alloys; varying temperatures; and different types or strengths of magnets.

A Sample Research Problem in Earth Science

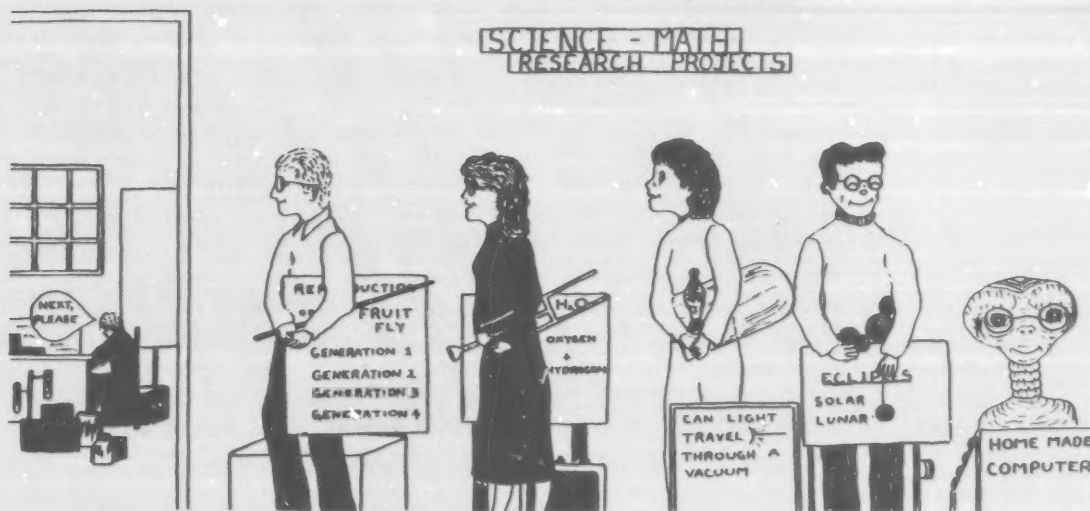
Title: *The Effect of Wind Erosion and Deposition on Sand, Clay, and Gravel*

BACKGROUND INFORMATION

Deserts, plowed fields and beaches are prime targets for wind erosion. These areas contain material that is at the earth's surface and thus exposed to the movement of air. Wind erosion is a factor of wind speed, and of the size and type of materials carried by the wind. (Roble, Murray, and Rice, Earth Science, New Jersey: Prentice-Hall, 1981). The development of different types of windbreaks is an area of active research that has major commercial and ecological importance.

SUGGESTED EXPERIMENTAL DESIGN

A hand-held hair dryer or electric fan may be used to direct a flow of air into a pan containing several materials. Data may be recorded as a function of wind speed, distance, and the relative effect of obstacles (wind breaks) on the erosion process.



A Sample Project in Mathematics

Title: Can a Power of 2 Begin with the Digit 7?

BACKGROUND INFORMATION

If we work in decimal notation, and calculate powers of 2, we find that the units digits form a repeating cycle:

$2^1 = 2$	$2^6 = 64$	$2^{11} = 2048$
$2^2 = 4$	$2^7 = 128$	$2^{12} = 4096$
$2^3 = 8$	$2^8 = 256$	.
$2^4 = 16$	$2^9 = 512$	.
$2^5 = 32$	$2^{10} = 1024$	.

Using the theory of congruences from number theory, we can prove that this cycle will continue and that powers of any number in any base will have a cycle of units digits.

For a given base, and powers of a given number, we can predict what the length of the cycle will be.

If we keep track of the last two digits of powers of 2 (in decimal notation), we are simply keeping track of a units "digit" in a scale of notation using base 100. Hence the final two digits of powers of 2 will also form a pattern, as will the final 3 digits, the final 4 digits, and so on. But what if we look at the initial (leftmost) digit of powers of 2? Some quick hand calculation will reveal a pattern: The cycle 1, 2, 4, 8, 1, 3, 6, 1, 2, 5, repeats. Since there is no apparent reason for this pattern, we might check to see if it continues for higher exponents, using a computer program.

We find, in fact, that the pattern begins to break down. We would like a theoretical explanation for the behavior of the initial digits of powers of 2 in decimal notation.

SUGGESTED MODES OF INVESTIGATION

It is easier to take the logarithms of the numbers concerned. If the number 2^n is an m -digit number beginning with the digit d , then

$$d \cdot 10^{m-1} < 2^n < (d+1) \cdot 10^{m-1}$$

$$\text{or } m-1 + \log d < n \log 2 < (m-1) + \log (d+1).$$

This observation leads to a study of the multiples of the irrational number $\log$ (Insert), and how they lie between the integers. This, in turn, leads to a consideration of the real numbers taken modulo the rationals, and some rather deep results about the group structure of the real numbers.

References:

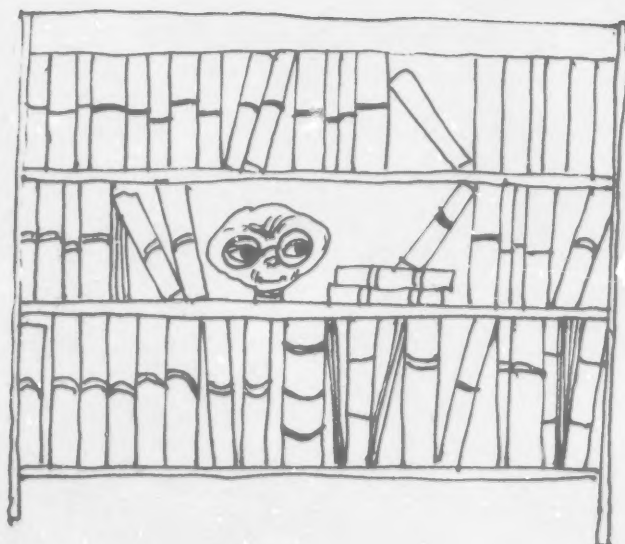
Bourbaki, Nicolas. General Topology, New York: Addison-Wesley, 1966

Hardy, G.H., and Wright, E.M., Introduction to the Theory of Numbers, London: Oxford University Press, 1960.

Gauss G.P., Disquisitiones Arithmeticae, (Translated by Arthur A. Clarke), New Haven: Yale University Press, 1966.

17.

TEXTS AND REFERENCES



PART I — SCIENCE

Textbooks and Class Sets

This bibliography is a partial listing. Class sets of textbooks are recommended for the school library, but the textbook sets most needed in a school may vary with its evolving research program.

A Suggested Textbook for the Classroom

Biological Sciences Curriculum Study (BSCS). Biological Science: Interaction of Experiments and Ideas. 3rd ed. Englewood Cliffs, N.J.: Prentice-Hall, Inc.

Suggested Class Sets for School Library

<u>Number of copies</u>	<u>Title</u>
10	Buchsbaum, Ralph. <u>Animals Without Backbones</u> . 2nd ed. Chicago: University of Chicago Press, Ill., 1948.
30	Galstoff, et al. <u>Culture Methods for Invertebrate Animals</u> . New York: Dover, 1959
30	Morholt, Evelyn, et al. <u>A Source Book for the Biological Sciences</u> . 2nd ed. New York: Harcourt, Brace & World, 1966.
15	Joseph, Alexander, et al. <u>A Source Book for the Physical Sciences</u> . New York: Harcourt, Brace & World, Inc. 1961.

Selected Bibliography for Students and Teachers

General Science

American Association for the Advancement of Science and National Science Foundation. New York: The AAAS Science Book List. 1959.

An Inexpensive Science Library. New York: AAAS, 1959.

A Selected List of Career Guidance Publications for High School Students. 1959.

The Traveling High School Science Library. New York: AAAS, 5th ed., 1959.

Asimov, I. Only a Trillion: Speculations and Explorations on the Miracles of Science. New York: Abelard-Schuman, 1957.

Calder, R. Science in Our Lives. New York: Signet Key, 1955.

Campbell, N. What Is Science? New York: Dover, 1952.

Gamov, G. One, Two, Three...Infinity: Facts and Speculations of Science. Mentor, 1953.

Goldstein, P. How to Do an Experiment. New York: Harcourt, Brace, 1957.

Schrodinger, E. C. Science, Theory and Man. Dover: 1957.

Thomson, J. A. Riddles of Science. New York: Premier, 1958.

Weyl, H. Philosophy of Mathematics and Natural Science. Princeton: Princeton University Press, 1959.

Aeronautics

Bizomy, M.T., ed. The Space Encyclopedia. New York: E.P. Dutton, 1957. Ley, W. Satellites, Rockets and Outer Space. New American Library, 1958.

Agriculture

Archer, S. C. Soil Conservation. Norman Okla.: University of Oklahoma, 1956.

Cook, J. G. The Fight for Food. New York: Dial Press, 1957.

Biology

Hardin, G. Biology: Its Principles and Implications. 2nd ed. San Francisco: W.H. Freeman, 1966.

Johnson, W.H. and W.C. Steere. This Is Life: Essays in Modern Biology. New York: Holt, Rinehart and Winston, 1962.

Simpson, G.G. et al. Life: An Introduction To Biology. 2d ed. New York: Harcourt, Brace & World, 1965.

Weisz, P.B. The Science of Biology. 2d ed. New York: McGraw-Hill, 1963.

BIOCHEMISTRY AND BIOPHYSICS

Baldwin, E. Dynamic Aspects of Biochemistry. London: Cambridge University Press, 1957.

Barry, J.M. Molecular Biology: Genes and the Chemical Control of Living Cells. Englewood Cliffs, N.J.: Prentice-Hall, 1964

Campbell, F.N. and G.D. Grenville. Essays in Biochemistry. 2 vols. New York: Academic Press, 1966.

Cheldelin, V.H. and R.W. Newburgh. The Chemistry of Some Life Processes. New York: Reinhold, 1964.

Crick, F.H.C. Of Molecules and Men. Seattle: University of Washington Press, 1965.

Edsall, J.T., and J. Wyman. Biophysical Chemistry. Vol. I. New York: Academic Press, 1958.

Fox, S. W., ed. The Origins of Prebiological Systems and of Their Molecular Matrices. New York: Academic Press, 1965.

Giese, A.C. Cell Physiology. Philadelphia: W.B. Saunders, 1962.

Grunwald, E., and R.H. Johnson. Atoms, Molecules and Chemical Change. Englewood Cliffs, N.J.: Prentice-Hall, 1960.

Lagowski, J.J. The Chemical Bond. Boston: Houghton Mifflin, 1966.

Lessing, L. Understanding Chemistry. New York: New American Library, 1959.

Setlow, R.B. and E.C. Pollard. Molecular Biophysics. Reading, Mass.: Addison-Wesley, 1962.

Whittingham, C.P. The Chemistry of Plant Processes. New York: Philosophical Library, 1965.

CELLS AND TISSUES

- Butler, J.A.V. The Life of the Cell: Its Nature, Origin, and Development. New York: Basic Books, 1964.
- Clark, W.E.L. Tissues of the Body. Oxford: Clarendon Press, 1958.
- Gerard, R.W. Unresting Cells. New York: Harper & Row, 1961.
- Giese, A.C. Cell Physiology. 2nd. ed. Philadelphia: W.B. Saunders, 1962.
- Loewy, A. and P. Siekevitz. Cell Structure and Function. New York: Holt, Rinehart and Winston, 1963.
- McElroy, W.D. Cell Physiology and Biochemistry. Foundations of Modern Biology Series. Englewood Cliffs, N.J.: Prentice-Hall, 1964.
- Mercer, E. H. Cells, Their Structure and Function. New York: Doubleday, 1962.
- Monroy, A. Chemistry and Physiology of Fertilization. New York: Holt, Rinehart and Winston, 1965.
- Porter, K.R., and M.A. Bonneville. An Introduction to the Fine Structure of Cells and Tissues. 2nd ed., Philadelphia: Lea & Febiger, 1964.
- Robertis, E., et al. General Cytology. Philadelphia: W.B. Saunders, 1960.
- Spratt, N.T. Introduction to Cell Differentiation. New York: Reinhold, 1964.
- Swanson, Carl P. The Cell. Englewood Cliffs, N.J.: Prentice-Hall, 1964.

PLANTS

- Albersheim, P. "The Walls of Growing Plant Cells." Scientific American, April 1975.
- Bonner, J., and A. Galston. Principles of Plant Physiology. San Francisco: W.H. Freeman, 1952.
- Baker, H.G. "Evolutionary Mechanisms in Pollination Biology." Science, 139 (1963), 877.
- Brill, W.J. "Biological Nitrogen Fixation." Scientific American, 236 236 (1977), 68.

Chapman, V.J. The Algae. New York: St. Martin's Press, 1962.

Christensen, C.M. Molds and Man: An Introduction to the Fungi. Minneapolis: University of Minnesota Press, 1961.

Doyle, W.T. Nonvascular Plants: Form and Function. Belmont: Calif.: Wadsworth, 1964.

Epstein, E. Mineral Nutrition of Plants: Principles and Perspectives. New York: John Wiley & Sons, 1973.

"Roots." Scientific American, Aug. 1972.

Esau, K. Anatomy of Seed Plants, 2nd ed. New York: John Wiley & Sons, 1967.

Galston, W.W., and P.J. Davies. Control Mechanisms in Plant Development. Englewood Cliffs, N.J.: Prentice-Hall, 1970.

N.J. Hardy, R.W.F., and V.D. Havelka. "Nitrogen Fixation Research: A Key to World Food?" Science, 188 (1975), 633.

Galston, A. The Life of the Green Plant. Englewood Cliffs, N.J.: Prentice-Hall, 1964.

Greulach, V.A., and J.E. Adams. Plants: An Introduction to Modern Botany. 2nd ed. New York: John Wiley & Sons, 1967.

James, W.O. An Introduction to Plant Physiology. 6th ed. New York: Oxford University Press, 1963.

Jensen, W.A., and L.G. Kavaljian, eds. Plant Biology Today. Belmont, Calif.: Wadsworth, 1963.

Lee, A.E., and C. Heimsch. Development and Structure of Plants. New York: Holt, Rinehart and Winston, 1962.

Rutter, A.J. Transpirations. Oxford: Oxford University Press, 1972.

Sigurbjornsson, Bjorn. "Induced Mutations in Plants." Scientific American. Jan. 1971.

Sporne, K.R. The Mysterious Origin of Flowering Plants. Burlington, N.C.: Carolina Biological Supply Company, 1971.

Steeves, T.A., and I.M. Sussex. Patterns in Plant Development. Englewood Cliffs, N.J.: Prentice-Hall, 1972.

Wade, N. "Green Revolution (1): A Just Technology Often Unjust in Use." Science, 186 1974), 1093.

ANIMALS

Asimov, I. The Human Brain. Boston: Houghton Mifflin, 1965.

Barnes, R.D. Invertebrate Zoology. Philadelphia: Saunders, 1964.

Best, C.H., and N.B. Taylor. The Human Body: Its Anatomy and Physiology. 4th ed., New York: Holt Rinehart and Winston, 1963.

Carlson, E., and V. Johnson. The Machinery of the Body. 5th ed. Chicago: University of Chicago Press, 1961.

Darling, F.F. A Herd of Red Deer. The Natural History Library, Garden City, N.Y.: Anchor Books, 1964.

Eimerl, S., et al. The Primates. New York: Time, 1965.

Farb, P. et al. The Insects. New York: Time, 1962.

Graubard, M. Circulation and Respiration: The Evolution of an Idea. New York: Harcourt, Brace & World, 1964.

Gray, J. How Animals Move. Rev. ed. London: Cambridge University Press, 1959.

Griffin, D.R. Animal Structure and Function. New York: Holt, Rinehart and Winston, 1952.

Houssay, B.A., et al., Human Physiology. New York: McGraw-Hill, 1955.

Jacob, S.W., and C.A. Francone. Structure and Function in Man. Philadelphia: W.B. Saunders, 1965.

Michelmores, S. Sexual Reproduction. New York: The American Museum of Natural History, 1966.

Moment, G.B. General Zoology. 2nd ed. Boston: Houghton Mifflin, 1967.

Moore, J.A. Principles of Zoology. New York: Oxford University Press, 1957.

Morley, D.W. The Ant World. Baltimore: Penguin Books, 1953.

Nalbandov, A.V. Reproductive Physiology. 2nd ed. San Francisco: W.H. Freeman, 1964.

Nottingham University School of Agriculture. Soil Zoology. D.K. McE. Kevan, ed. London: Buttersworth, 1955.

Osmanney, F.D., et al. The Fishes. New York: Time, 1963.

Peterson, R.T., et al. The Birds. New York: Time, 1963.

Prosser, C.L., and F.A. Brown, Jr. Comparative Animal Physiology. Philadelphia: W.B. Saunders, 1961.

Riedman, S.R. Our Hormones and How They Work. New York: Collier Books, 1962.

Romer, A.S. The Vertebrate Body. 3d ed. Philadelphia: W.B. Saunders, 1962.

----- The Vertebrate Story. 4th ed. Chicago: University of Chicago Press, 1962.

Ruch, T.C., and J.F. Fulton. Medical Physiology and Biophysics. Philadelphia: W.B. Saunders, 1960.

Schmidt, K.P., and R.F. Inger. Living Reptiles of the World. New York: Doubleday, 1957.

Schmidt-Nelson, K. Animal Physiology. Englewood Cliffs, N.J.: Prentice-Hall, 1964.

Storer, T.I., and R.L. Usinger. General Zoology. 4th ed. New York: McGraw-Hill, 1965.

Tinbergen, N. The Herring Gull's World. New York: Basic Books, 1961.

Turner, C.D. General Endocrinology. 4th ed. Philadelphia: W.B. Saunders, 1966.

Van Lyne, J., and A.J. Berger. Fundamentals of Ornithology. Science Editions, New York: John Wiley & Sons, 1959.

Young, J.Z. The Life of Vertebrates. 2nd ed. Oxford: Oxford University Press, 1962.

BIOSPHERE

Amos, W.H. The Life of The Seashore. New York: McGraw-Hill, 1966.

Bourliere, F. The Natural History of Mammals. New York: Alfred A. Knopf, 1964.

Brouwer, A. General Palaeontology. Chicago: University of Chicago Press, 1967.

Carson, R. The Sea Around Us. New York: Simon and Schuster, 1958.

Coker, R.E. Streams, Lakes, Ponds. Chapel Hill, N.C.: University of North Carolina Press, 1954.

Colbert, E.H. Men and Dinosaurs. New York: E.P. Dutton, 1968.

Darlington, P.J., Jr. Zoogeography: The Geographical Distribution of Animals. New York: John Wiley & Sons, 1957.

Darrah, W.C. Principles of Paleobotany. New York: The Ronald Press, 1960.

Fenton, C.L., and M.A. Fenton. The Fossil Book: A Record of Prehistoric Life. Garden City, N.Y.: Doubleday, 1958.

Gleason, H.A., and A. Cronquist. The Natural Geography of Plants. New York: Columbia University Press, 1964.

Goldring, W. Handbook of Paleontology for Beginners and Amateurs. Part I, "The Fossils." Ithaca, N.Y.: Paleontological Research Institution, 1960.

Good, R.O. Geography of the Flowering Plants. New York: John Wiley & Sons, 1964.

Hanson, H.C., and E.D. Churchill. The Plant Community. New York: Reinhold, 1961.

Hardy, A.C. The Open Sea: Its Natural History. Part I, "The World of Plankton." Boston: Houghton Mifflin, 1957.

Hesse, R., et al. Ecological Animal Geography. New York: John Wiley & Sons, 1951.

Matthews, W.H. Fossils: An Introduction to Prehistoric Life. New York: Barnes and Noble, 1962.

McCormick, J. The Life of the Forest. New York: McGraw-Hill, 1966.

Niering, W.A. The Life of the Marsh. New York: McGraw-Hill, 1967.

- Prings, H., and M. Prings. Animal Communication. New York: Blaisdell, 1964.
- Huxley, and L. Koch. Animal Language. New York: Grosset & Dunlap, 1964.
- Klopfer, P.H. Behavioral aspects of Ecology. Englewood Cliffs, N.J.: Prentice-Hall, 1962.
- Klopfer, P.H., and J.P. Hailman. An Introduction to Animal Behavior. Englewood Cliffs, N.J.: Prentice-Hall, 1967.
- Lorenz, K.Z. Kings Solomon's Ring. New York: Thomas Y. Crowell, 1952.
- Lorenz, K.Z. On Aggression. New York: Harcourt, Brace & World, 1966.
- Marler, P.R., and W.J. Hamilton III. Mechanisms of Animal Behavior. New York: John Wiley & Sons, 1966.
- McGaugh, J.L., et al., Psychobiology. San Francisco: W.H. Freeman, 1967.
- Portmann, A. Animals as Social Beings. New York: The Viking Press, 1961.
- Rheingold, H. Maternal Behavior in Mammals. New York: John Wiley & Sons, 1963.
- Roe, A., and G.G. Simpson. Behavior and Evolution. New Haven: Yale University Press, 1958.
- Scott, J.P. Animal Behavior. New York: Doubleday, 1963.
- Southwick, C.H. Primate Social Behavior: An Enduring Problem. Princeton, N.J.: D. Van Nostrand, 1963.
- Thorpe, W.H. Learning and Instinct in Animals. Cambridge, MA.: Harvard University Press, 1958.
- Tinbergen, N., et al. Animal Behavior. New York: Time, 1965.
- Tinbergen, N. Social Behavior in Animals. London: Butler & Tanner, 1965.
- . A Study of Instinct. Fair Lawn, N.J.: Clarendon Press, 1951.

Ramson, J.E. Fossils In America. New York: Harper and Row, 1965.

Ricketts, E.F., and J. Calvin. Between Pacific Tides. 3rd ed., rev. by J.W. Hedgpeth. Palo Alto, Calif.: Stanford University Press, 1962.

Romer, A.S. Vertebrate Paleontology. 3rd ed. Chicago: University of Chicago Press, 1966.

Russell, E.J. The World of the Soil. London: Longmans, Green, 1950.

Simpson, G.G. Life of the Past: An Introduction to Paleontology. New Haven: Yale University Press, 1953.

Sverdrup, H.U., et al. The Oceans: Their Physics, Chemistry, and General Biology. Englewood Cliffs, N.J.: Prentice-Hall, 1942.

BEHAVIOR

Ardrey, R. The Territorial Imperative. New York: Atheneum, 1966.

Barash, D.P. Sociobiology and Behavior. New York and Amsterdam: Elsevier, 1977.

Barnett, S.A. Instinct and Intelligence: Behavior of Animals and Man. Englewood Cliffs, N.J.: Prentice-Hall, 1967.

Brown, J.L. The Evolution of Behavior. New York: W.W. Norton, 1975.

Chomsky, N. Language and Mind. New York: Harcourt Brace Jovanovich, 1972.

Christian, J.J. "Social Subordination. Population Density, and Mammalian Evolution." Science 168 (1970), 84.

Darwin, C. The Descent of Man, and Selection in Relation to Sex. New York: Appleton, 1871.

Dawkins, R. The Selfish Gene. New York and Oxford: Oxford University Press, 1976.

Ehrman, L., and P.A. Parsons. The Genetics of Behavior. Sunderland, Mass.: Sinauer Associates, 1976.

Van Der Kloot, W.G. Behavior. New York: Holt, Rinehart and Winston, 1968.

Wynne-Edwards, V.C. Animal Dispersion In Relation to Social Behavior. London: Oliver & Boyd, 1962.

Heredity and Development

Allison, A.C. "Sickle Cells and Evolution." Scientific American, Aug. 1956.

Avery, O.T., et al. "Studies on the Chemical Nature of the Substance Inducing Transformation of Pneumococcal Types." Journal of Experimental Medicine 79 (1944), 137.

Beagle, G., and M. Beadle. The Language of Life. New York: Doubleday, 1966.

Bishop, J.A., and L.M. Cook. "Moths, Melanism and Clean Air." Scientific American, Jan. 1975.

Bonner, D. Heredity. Englewood Cliffs, N.J.: Prentice-Hall, 1961.

Borek, E. The Code of Life. New York: Columbia University Press, 1965.

Boyd, W. Genetics and the Races of Man. Boston: Little, Brown, 1958.

Brewbaker, H.L. Agricultural Genetics. Englewood Cliffs, N.J.: Prentice-Hall, 1964.

Crick, F.H.C. "The Genetic Code." Scientific American, Oct 1966.

_____ "The Genetic Code III." Scientific American, Oct. 1973.

Darnell, J.E. "Implications of RNA-RNA Splicing in the Evolution of Eukaryote Cells." Science 202 (1978), 1257.

Darwin, C. On the Origin of Species. A facsimile of the first edition. Cambridge, MA.: Harvard University Press, 1859, 1966.

Dawkins, R. The Selfish Gene. New York and Oxford: Oxford Press, 1976.

de Beer, G. "Evolution." The New Encyclopedia Britannica, 1974 ed.

Dickerson, R.E. "The Structure and History of an Ancient Protein." Scientific American, April 1972.

Golding, W. The Inheritors. New York: Harcourt, Brace & World, 1963.

Hartman, P.E., and S.R. Suskind. Gene Action. Englewood Cliffs, N.J.: Prentice-Hall, 1965.

Kendrew, J.C. The Thread of Life. Cambridge, Mass.: Harvard University Press, 1966.

King, R.C. Genetics. 2nd ed. New York: Oxford University Press, 1965.

Levine, R.P. Genetics. New York: Holt, Rinehart and Winston, 1963.

McKusick, V.A. Human Genetics. Englewood Cliffs, N.J.: Prentice-Hall, 1964.

Moore, R. The Coil of Life. New York: Alfred A. Knopf, 1961.

Roslansky, J.O., ed. Genetics and the Future of Man. New York: Appleton-Century-Crofts, 1966.

Rugh, R. Vertebrate Embryology: The Dynamics of Development. New York: Harcourt, Brace & World, 1965.

Stahl, F.W. The Mechanics of Inheritance. Englewood Cliffs, N.J.: Prentice-Hall, 1964.

Stern, C., and E.R. Sherwood. The Origin of Genetics. San Francisco: W.H. Freeman, 1966.

Strehler, B.L. Time, Cells and Aging. New York: Academic Press, 1962.

Strickberger, M.W. Experiments in Genetics with Drosophila. New York: John Wiley & Sons, 1962.

Sturtevant, A.H. A History of Genetics. New York: Harper & Row, 1965.

Sussman, M. Animal Growth and Development. 2d ed., Englewood Cliffs, N.J.: Prentice-Hall, 1964.

Waddington, C.H. Principles of Development and Differentiation. New York: Macmillan, 1966.

Watson, J.D. The Double Helix. New York: Atheneum, 1968.

ECOLOGY

Ager, D.V. Principles of Paleoecology. New York: McGraw-Hill, 1963.

Andrewartha, H.C. Introduction to the Study of Animal Populations. Chicago: University of Chicago Press, 1961.

Connell, J.H., et al., eds. Readings in Ecology and Ecological Genetics. New York: Harper & Row, 1970.

Dowdeswell, W.H. Animal Ecology. New York: Harper & Row, 1961.

Elton, C.S. The Ecology of Invasions by Animal and Plants. New York: John Wiley & Sons, 1958.

Fiennes, R. Man, Nature and Disease. New York: New American Library, 1965.

Frey, D.G. Limnology in North America. Madison: University of Wisconsin Press, 1963.

Hanson, H.C., and E.D. Churchill. The Plant Community. New York: Reinhold, 1961.

Hardin, G. Nature and Man's Fate. New York: New American Library, 1961.

Lack, D. Population Studies of Birds. Oxford: Oxford University Press, 1966.

Murdoch, W.W., ed. Environment. 3rd ed. Basic readings. Stamford, Conn.: Sinauer, 1975.

National Academy of Sciences. The Growth of World Population. New York: National Research Council Publications, 1963.

Odum, E.P. Ecology. New York: Holt, Rinehart and Winston, 1963.

Oosting, H.J. The Study of Plant Communities. San Francisco: W.H. Freeman, 1956.

Phillips, E.A. Field Ecology. A BSCS Laboratory Block. Boston: D.C. Heath, 1964.

Phillipson, J. Ecological Energetics. New York: St. Martin's Press, 1966.

Ricklefs, R.E. Ecology, 2nd ed. Newton, Mass.: Chiron Press, 1978.

Ruttner, F. Fundamentals of Limnology. 3rd ed. Toronto: University of Toronto Press, 1963.

Schaller, G.B. The Serengeti Lion. Chicago: University of Chicago Press, 1972.

Schaller, G.B. The Biosphere. San Francisco: W.H. Freeman, 1970.

Shepard, P., and O.McKinley, eds. The Subversive Science: Essays Toward and Ecology of Man. Boston: Houghton Mifflin, 1969.

Terborgh, J. "Preservation of Natural Diversity, the Problem of Extinction-prone Species." Bioscience, 24 (1974), 715.

Wilson, E.O., ed. Ecology, Evolution and Population Biology. San Francisco: W.H. Freeman, 1974.

Wilson, E.O., and W.H. Bossert. A Primer of Population Biology. Sunderland, Mass.: Sinauer, 1971.

EVOLUTION

- Bates, M. The Forest and the Sea. Toronto: Random House, 1960.
- Bates, M. Man in Nature. Englewood Cliffs, N.J.: Prentice-Hall, 1961.
- Becker, H.F. Resources for Tomorrow. New York: Holt, Rinehart and Winston, 1964.
- Billings, W.D. Plants and the Ecosystem. New York: Macmillan, 1965.
- Brown, Harrison. The Challenge of Man's Future. New York: The Viking Press, 1956.
- Browning, T.O. Animal Populations. New York: Harper & Row, 1963.
- Cloudsley-Thompson, J.L. Microecology. New York: St. Martin's Press, 1967.
- Carson, R. Silent Spring. Boston: Houghton Mifflin, 1962.
- Colbert, E.H. Evolution of the Vertebrates. New York: John Wiley & Sons, 1961.
- Coon, C.S. The Story of Man. 2nd ed. rev. New York: Alfred A. Knopf, 1962.
- Dart, R., and D. Craig. Adventures with the Missing Link. New York: Harper & Row, 1959.
- Delevoryas, T. Plant Diversification. Modern Biology Series. New York: Holt, Rinehart and Winston, 1966.
- Dobzhansky, T. Mankind Evolving. New Haven: Yale University Press, 1962.
- Eiseley, L. Darwin's Century. New York: Doubleday, 1961.
- Hanson, E.D. Animal Diversity. 2nd ed. Englewood Cliffs, N.J.: Prentice-Hall, 1964.
- Huxley, J. Evolution in Action. New York: New American Library, 1957.
- Lasker, G.W. Human Evolution. New York: Holt, Rinehart and Winston, 1963.

Montagu, A. Man: His First Million Years. New York:
New American Library of World Literature, 1962.

Moore, R., et al. Evolution. New York: Time, 1962.

Simpson, G.C. The Meaning of Evolution. New York:
New American Library, 1960.

Srb, A.M., and B. Wallace. Adaptation. 2nd ed.
Englewood Cliffs, N.J.: Prentice-Hall, 1964.

Stebbins, G.L. Processes of Organic Evolution.
Englewood Cliffs, N.J.: Prentice-Hall, 1966.

Stirton, R.A. Time, Life and Man. New York: John
Wiley & Sons, 1959.

Wendt, H. Before the Deluge. Garden City, N.Y.:
Doubleday, 1968.

Volpe, E.P. Understanding Evolution. Dubuque, Iowa:
William C. Brown, 1967.

TAXONOMY

Benson, L. Plant Classification. Boston: D.C. Heath, 1957.

Blair, W.F. et al. Vertebrates of the United States. New York: McGraw-Hill, 1957.

Lawrence, G.H. Taxonomy of Vascular Plants. London: Macmillan, 1952.

----- Introduction to Plant Taxonomy.
New York: Macmillan, 1955.

Porter, C.L. Taxonomy of Flowering Plants. San Francisco: W.H. Freeman, 1961.

Rothschild, N.M.V. A Classification of Living Animals. New York: John Wiley & Sons, 1961.

Savory, T. Naming the Living World. New York: John Wiley & Sons, 1963.

Scagel, R.F. et al. An Evolutionary Survey of the Plant Kingdom. Belmont, Calif.: Wadsworth, 1965.

Simpson, G.G. Principles of Animal Taxonomy. New York: Columbia University Press, 1961.

Sokal, R.R., and P.H.A. Sneath. Principles of Numerical Taxonomy. San Francisco: W.H. Freeman, 1963.

Ward, H.B. and G.C. Whipple. Fresh-water Biology. 2nd ed. W.T. Edmonson, ed. New York: John Wiley & Sons, 1959.

Chemistry

- Amoore, J.S., et al. "The Stereochemical Theory of Odor." Science American, Feb. 1964, p. 42.
- Anderson, E.V. "Gasohol: Energy Mountain or Molehill?" Chemical and Engineering News, July 1978, p. 8.
- Anderson, K.K. and D.T. Bernstein. "T-Butanethol and the Striped Skunk." Journal of Chemical Education, 55 (1978), 159.
- "Atoms in Living Color." Chemistry, Jan. 1979, p. 710.
- Bassow, H. "The Great Spray Can Debate." Journal of Chemical Education, 54 (1977), 371.
- Bolin, B. 1970. "The Carbon Cycle." Science American, Sept. 1970, p. 124.
- Bragg, R.W., et al., "Sweet Organic Chemistry." Journal of Chemical Education, 55 (1978), 281.
- Brown, R.A. "Creativity, Discovery and Science." Journal of Chemical Education, 54 (1977), 720.
- Brown, R.A., and R.G. Luckcok. "Dreams, Daydreams, and Discovery." Journal of Chemical Education, 55 (1977), 694.
- Burwell, C.C. "Solar Biomass Energy: An Overview of U.S. Potential." Science, 199 (1978), 1041.
- Childs, P.E. "Chemicals From Wood." Education in Chemistry, May 1978, p. 79.
- Christoudouleas, N.D. "Particles, Waves and the Interpretation of Quantum Mechanics." Journal of Chemical Education 52 (1975), 573.
- Clevenger, S. "Flower Pigments." Science American, June, 1965, p. 85.
- Cutcher, P. "Stratospheric Ozone Depletion and Solar Ultraviolet Radiation on Earth." Science, 184 (1974), 13.
- Demchik, M.J. and V.C. Demchik. "Size and Shape of a Molecule." Journal of Chemical Education, 48 (1971), 770.
- Donovan, R.J. 1978. "Chemistry and Pollution of the Stratosphere." Education in Chemistry, July, p.110.
- Irago, R.J. 1967. "Donor-Acceptor Interactions." Chemistry in Britain 3:516.

Frieden, E. "The Chemical Elements of Life." Science American, July 1972, p.52.

Gutman, V. "Ionizing Solvents." Chemistry in Britain, 7 (1971), 102.

Hall, F.M. "The Theory of Acid and Bases," Education in Chemistry, 1 (1964), 91.

Hammel, H.T. "Colligative Properties of a Solution." Science, 192 (1976), 748.

Hauser, E.A. "The History of Colloid Science." Journal of Chemical Education 32 (1955), 2.

Hobbs, P.V., H. Harrison, and E. Robinson. "Atmospheric Effects of Pollutants." Science, 183: (1974), 909.

Hocking, M.B. "The Chemistry of Oil Recovery from Bituminous Sands." Journal of Chemical Education 54: (1977), 725.

Kauffman, G.B. "Pittacal - The First Synthetic Dyestuff." Journal of Chemical Education, 54: (1977), 295.

Kauffman, G.B., and R.P. Cinla. "Emil Fischer's Discovery of Phenylhydrazine." Journal of Chemical Education 54 (1977), 725.

Kieffer, W.F. The Mole Concept in Chemistry. New York: Reinhold, 1962.

Kolb, D. "A Pill for Birth Control." Journal of Chemical Education 55 (1978), 591.

Lambert, J.B. "The Shapes of Organic Molecules." Science American, Jan. 1970, p. 58.

Lappert, M.F. "Organometallic Chemistry." Chemistry in Britain, 5 (1969), 342.

"Lasers, The Light Fantastic." Journal of Chemical Education, 55 (1978), 529.

Lee, D.M., and N.D. Mermin. "Ideal Solutions." Science American, Dec. 1976, p.56.

Meyers, R.T.. "The Strength of Hydrolics Acids." Journal of Chemistry Education 53 (1976), 17.

Mowery, D.F. Jr. "Criteria for Optical Activity in Organic Molecules." Journal of Chemical Education 46 (1969), 269.

Oates, W.A. "Ideal Solutions." Journal of Chemical Education 46 (1969), 501.

Osborn, E.F. "Coal and the Present Energy Situation." Science, 183 (1974), 477.

Pierce, J.R. "The Fuel Consumption of Automobiles." Science American, Jan. 1975, p. 34.

Peterson, R.W. "Impacts of Technology." American Scientist, 67: (1979), 28.

Pilar, F.L. "The Poisonous Nature of Carbon Dioxide (128 Years Ago)." Journal of Chemical Education, 52 (1975), 791.

Pryor, W.A. "Free Radicals and Aging." Chemical and Engineering News, June 1971, p. 34.

"Quantum Mechanics You Can See." Science News, 106 (1974), 68.

Robinson, A.L. "Metrology: A More Accurate Value for Avogadro's Number," Science, 185 (1974), 1037.

Schlegel, J.M. "Lewis Acid-Base Titration in Fused Salts." Journal of Chemical Education 43 (1966), 362.

Shapiro, I.S. "Future Sources of Organic Raw Materials." Science, 202 (1978), 287.

Shapiro, J.S., et al. "Relationship between Rate of Evaporation and Vapor Pressure of Binary Systems." Journal of Chemical Education, 52 (1975), 439.

Singh, H.B. et al. "Atmospheric Halocarbons, Hydrocarbons, and Sulfur Hexafluoride: Global Distribution, Sources, and Sinks." Science, 203 (1979), 899.

Snell, F.D., and C.T. Snell. "Syndets and Surfactants." Journal of Chemical Education, 46 (1969), 710.

Socrates, G. "SI Units" (International System of Units). Journal of Chemical Education, 46 (1969), 710.

Walker, J. "Drops of Liquid Can Be Made to Float on the Liquid. What Makes Them Do So?" Science American, June 1978, p. 151.

Werner, A.E. "Scientific Methods in Art and Archeology," Chemistry in Britain, 6 (1970), 55.

Wishnack, J.S. "Formation of Nitrosamines in Food and in the Digestive System." Journal of Chemical Education 54 (1977), 440.

Wotiz, J.H. "The Discovery of Saccharin." Journal of Chemical Education, 55 (1978), 161.

Earth Science

Adams, G.F. and J. Wyckoff. Lanaforms. Racine, Wisconsin: Golden Books, 1971.

Battan, Louis J. "Killers from the Clouds." Natural History, April 1975, pp. 56-61.

Berendzen, R., et al. Man Discovers the Galaxies. New York: Neale Watson Academic Publication, 1976.

Bisque, R.E., et al. Earth Science: Patterns in Our Environment. Englewood Cliffs, N.J.: Prentice-Hall, 1975.

Bloom, A. L. The Surface of the Earth. Foundations of Earth Science Series. Englewood Cliffs, New Jersey: Prentice-Hall, 1969.

Bok, B. and P. Bok. The Milky Way. 5th ed. Cambridge, Mass.: Harvard University Press, 1981.

Brindze, R. Charting the Oceans. New York: Vanguard Press, 1972.

Cortright, E., ed. Apollo Expeditions to the Moon. Washington, D.C.: GPO, 1979.

Crickmay, C.H. The Work of the River. New York: Elsevier, 1974.

Dinley, D. Earth's Voyage Through Time. New York: Alfred A. Knopf, 1974.

Eddy, J.A., and R. Ise, eds. A New Sun: The Solar Results from Skylab. Washington D.C.: GPO, 1979.

Friedman, H. The Amazing Universe. Washington: D.C.: National Geographic Society, 1975.

Gamow, G. Gravity. Garden City, N.Y.: Doubleday, 1972.

- Gaposchkin, C. P. Stars and Clusters. Cambridge, Mass: Harvard University Press, 1979.
- Gentry, R.C. "Disaster from the Tropics." Natural History, Oct. 1973, pp. 45-55.
- Gilfond, H. Water: A Scarce Source. New York: Franklin A. Watts, 1978.
- Gingerich, O., ed. New Frontiers in Astronomy. San Francisco: W.H. Freeman, 1975.
- Gingerich, O. and K.R. Lang, eds. A Source Book in Astronomy and Astrophysics, 1900-1975. Cambridge, Mass.: Harvard University Press, 1979.
- Goldsmith, D. and T. Owen. The Search for Life in the Universe. Menlo Park, Calif.: Benjamin/Cummings, 1980.
- Goody, R., and J.C. Walker. Atmospheres. Englewood Cliffs, N.J.: Prentice-Hall, 1972.
- Haber, F.C. The Age of the World: Moses to Darwin. Greenwood Press, 1978.
- Hamblin, W.K. The Earth's Dynamic Systems. Minneapolis: Burgess, 1978.
- Judson, S., et al. Physical Geography. Englewood Cliffs, N.J.: Prentice-Hall, 1976.
- Leopold, L.B. Water: A Primer. San Francisco: W.H. Freeman, 1974.
- LePichon, X., et al. Plate Tectonics, New York: Elsevier, 1973.
- Lomnitz, C. Global Tectonics and Earthquake Risk. New York: Elsevier, 1974.
- Masursky, H., et al., eds. Apollo Over the Moon: A View from Orbit. Washington, D.C.: GPO, 1978.
- McEwan, M.J., and L.F. Phillips. The Chemistry of the Atmosphere. New York: The Halsted Press, 1975.
- Morrison, D.D. Voyager to Jupiter. Washington, D.C.: GPO, 1978.
- Viking Lander Imaging Team. The Martian Landscape. Washington, D.C.: GPO, 1978.

O'Leary, B., and J.K. Beatty, eds. The New Solar System. Cambridge, Mass.: Sky Publishing Co., 1981.

Reiter, F.R. "Rapid Rivers of Air." Natural History, March 1975, pp. 46-51.

Seeds, M.A. Astronomy: Selected Readings. Menlo Park, Calif.: Benjamin/Cummings, 1980.

Shapley, H., ed. Source Book in Astronomy, 1900-1950. Cambridge, Mass.: Harvard University Press, 1960.

Stephenson, W.A. Seaweed in Agriculture and Horticulture. Arlington Heights, Ill.: Maxicrop U.S.A., Inc., 1974.

Sullivan, W. Black Holes. New York: Doubleday, 1979.

Stokes, W.L. Essentials of Earth History: An Introduction to Historical Geology. Englewood Cliffs, N.J.: Prentice-Hall, 1973.

Tarling, D.H., ed. Evolution of the Earth's Crust. New York: Academic Press, 1977.

Thrower, N.J.W. Maps & Man. Englewood Cliffs, N.J.: Prentice-Hall, 1972.

Tuttle, S.D. Landscapes and Landforms. 2nd ed. Dubuque, Iowa: William C. Brown, 1975.

Van Dorn, W.G. Oceanography and Seamanship. New York: Dodd, Mead, 1974.

Williams, G. Continental Drift and Plate Tectonics. Columbus, Ohio: Charles E. Merrill, 1975.

Windley, B.F., ed. The History of the Earth. New York: John Wiley & Sons, 1976.

Physics

Alexander, R.M. Animal Mechanics. Seattle: University of Washington Press, 1968.

Ambrose, J.E. Building Structures Primer. New York: John Wiley & Sons, 1967.

Blum, H.R. Time's Arrow and Evolution. Rev. ed. Princeton: Princeton University Press, 1969.

- Boyle, W.S. "Light-wave Communications," Science American, Aug. 1977.
- Bronowski, J. The Ascent of Man. Boston: Little, Brown, 1974. Chapter 3.
- Cooper, B.M., and R.J. Noer. Revolution in Physics. New York: W.W. Norton, 1972.
- Cook, J.G. We Live by the Sun Dial. 1957.
- Cole, D.E. "The Wankel Engine." Science American, Aug. 1972, p. 14.
- Davidovits, P. Physics in Biology and Medicine. Englewood Cliffs, N.J.: Prentice-Hall, 1975.
- Gahlei, G. Dialogues Concerning Two New Sciences. New York: Dover, 1914.
- Hay, J.G. The Biomechanics of Sports Techniques. Englewood Cliffs, N.J.: Prentice-Hall, 1973.
- Jaffe, B. Michelson and the Speed of Light. New York: Doubleday, 1960.
- Jenkins, F.A. Fundamentals of Optics. 4th ed. New York: McGraw-Hill, 1975.
- Kopany, N.S. Fiber Optics: Principles and Applications. New York: Academic Press, 1967.
- Layzer, D. Dec. 1975. "Arrow of Time." Science American, Dec. 1975, p. 56.
- Lehninger, A.L. Bioenergetics: The Molecular Basis of Biological Energy Transformations. 2nd ed. Reading, Mass. W.A. Benjamin, 1971.
- Magie, W.F. Source Book in Physics. Cambridge, Mass.: Harvard University Press, 1963.
- Marston, E.H. The Dynamic Environment. New York: John Wiley & Sons, 1975.
- Meyer, H.W. History of Electricity and Magnetism. Cambridge, Mass.: M.I.T. Press, 1971.
- Meyer-Arendt, J.R. Introduction to Classical and Modern Optics. Englewood Cliffs, N.J.: Prentice-Hall, 1972.

Nash, L.K. Atomic-Molecular Theory. Cambridge, Mass.: Harvard University Press, 1950.

Orville, R.E. "The Lightning Discharge," Physics Teacher, 14 (1976), p.7.

Reinfeld, F. Rays: Visible and Invisible. Sterling, 1958.

Salvadori, M.G., and R. Heller. Structure in Architecture: The Building of Buildings. Englewood Cliffs, New Jersey: Prentice-Hall, 1975.

Schrodinger, E. What is Life? The Physical Aspect of the Living Cell. Cambridge: Cambridge University Press, 1969.

Sears, F.W. Optics. Reading, Mass.: Addison-Wesley, 1949.

Shonle, J.I. Environmental Applications of General Physics. Reading, Mass.: Addison-Wesley Publishing Co., Inc., 1974.

Stanford, A.L., Jr. Foundations of Biophysics. New York: Academic Press, Inc., 1975.

Williams, M., and H.R. Lissner. Biomechanics of Human Motion. Philadelphia: W.B. Saunders Company, 1962.

Wilson, D.G. "Alternative Automobile Engines." Science American, July 1978, p.39.

Science Research

TEXTS

Benrey, R. Ideas for Science Fair Projects. New York: Arco Publishing Company, Inc., 1963.

Sawyer, R.W., and R.A. Farmer. New Ideas for Science Fair Projects. New York: Arco, 1964.

Wald, G. 26 Afternoons of Biology. Reading, Mass.: Addison-Wesley Publishing Co., Inc., 1962.

PERIODICALS

Alexine, Sister M. April, 1973. "So You Want to Do Research." Science Teacher, April 1973, pp. 36-37.

Beck, C.F. 1961. "The Development and Present Status of School Science Fairs." Journal of Science Education, Oct. 1961, pp. 360-63.

Barnet, L.M. "Elementary Side of Science Fairs." The Texas Outlook, Jan. 1968, pp. 24-25.

Berlin, B.M. "New General Science Curriculum Features Direct Experimentation -- Secondary School Science Project Vitalizes General Science." Chicago Schools Journal, Nov. 1964, pp. 43, 63-67.

Bowers, E.J. "The Contribution of Science Fair Projects to Student Growth in Science." Unpublished master's thesis. The Ohio State University, Columbus, Ohio, 1958.

Bowles, D.R. "Who Makes a Scientist? You Do." The Grade School Teacher, Sept. 1966, pp 98-99, 166.

Brennan, R.J. "...Objectives." Unpublished master's thesis, The Ohio State University, Columbus, Ohio, 1961.

Calandra, A. "The New Science Curriculums." School Management, Nov. 1964, pp. 75-83.

Chase, G.D. "Radioisotopes - Should They Be a Part of Secondary Education?" The Science Teacher, Feb. 1964, pp. 31-33.

Cline, V.B., et al. "Creativity Tests and Achievement in High School Science." Journal of Applied Psychology, June 1963, pp. 184-89.

Dickie, J.K. "Thermal Differentiation in a Ripple Tank." Physics Teacher, Jan. 1973, p. 39.

Elkins, B. "Science Convention: Improved Version of a Science Fair." The Instructor, Oct. 1967, pp. 22-23.

Eyster, G.L. "Books, Libraries, and Science Fairs." Science Education, March 1969, pp. 171-74.

Fluke, D.J. "Radiation and High School Teaching." American Biology Teacher, Nov. 1960, pp. 496-97.

Francis, Sister J. "Potential Learnings in a Science Project." Catholic School Journal, Feb. 1962, pp. 45-47.

Huffmire, D.W. "Analysis of Independent Study Projects." Science Teacher, April 1962, p. 31.

Huffmire, F.W. "A Critical Appraisal of the Independent Study Project in Science." Science Education, April 1965, p. 68.

James, R.K. "Meaningful Research Experiences for High Ability Science Students." School Science and Mathematics, Oct. 1963, pp. 649-55.

Locke, E.A. "Correlates of Class and Out of Class Achievement." Journal of Educational Psychology, Oct. 1963, pp. 238-48.

Loughlin, W.T. "Open-House -- As a Teaching Tool." The Science Teacher, March 1971, pp. 47-48.

McCarley, M.F. "Planning for a Science Fair." The Instructor, Jan. 1967, p. 119.

Murdoch, A.C. "Evaluation of Experiments in High School Science." The Science Teacher, Dec. 1959, pp. 543-48.

"Nobel Winner and STS." Science News, Dec. 1972, p. 391.

Patton, E. Gibbes. "Declaration of Independence from Science Fairs." American Biology Teacher, Feb. 1971, p. 110.

Reinders, Sister M.H. "Radiation Biology in the High School Course." American Biology Teacher, Feb. 1959, pp. 60-61.

Rogers, A.R. "A Study of the Rhode Island Schools' Science Fair Program and Its Effectiveness as Reported by Former Exhibitors." Unpublished master's thesis. Rhode Island College of Education, 1960.

Shay, E.L. "Science Fairs, Not Contests -- A Reply to: 'Are Science Fair Really Science?'" The Science Teacher, April 1968, pp. 55-56.

Sadowski, B.S. "The Local Science Fair -- A Case Study." School Science and Mathematics, June 1968, pp. 491-94.

Starr, R.J. "Developing the Expertise for Sponsoring Student Projects." Science Teacher, Nov. 1972, pp. 39-40.

Thelen, L.J. "The Impact of Science Fairs on Student Exhibitors." Science Education, Dec. 1964, pp. 442-46.

West Coast Teacher's Summer Conference. "Science Projects As Stepping Stones to Career in Science." A Report to the Science Teaching Profession. Washington, D.C., National Science Teachers Association, 1956.

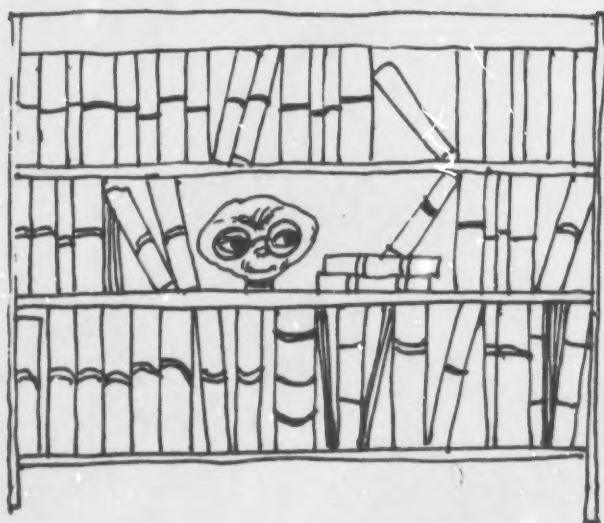
Yablonski, J.R. "High School Student Research -- Fact or Fancy." The Science Teacher, April 1964, p. 24.

Yager, R.E., and N.F. Dessel. "Selection Criteria for High Ability Science Students." Journal of Educational Research, Dec. 1963, pp. 193-96.

Zafferoni, J. "Activities That Evaluate." The Instructor, Jan. 1964, pp. 66-71.

17.

TEXTS AND REFERENCES



PART II — MATHEMATICS

BIBLIOGRAPHY — MATHEMATICS

Starred entries are recommended for purchase in class sets.

- I. Problem Solving: This title is used for a burgeoning area of psychological literature. Most of this material has little to offer students in a mathematics research class. The books cited below discuss problem solving specifically as related to mathematical content.

Polya, G. How to Solve It. New York: Anchor Books, 1957.

----- Induction and Analogy in Mathematics. Princeton, N.J.: Princeton University Press, 1954.

----- Mathematical Discovery. New York: Wiley & Sons, 1962.1962.

Wickelgren, W. How to Solve Problems. San Francisco: W. H. Freeman, 1974.

- II. General Texts: These books are encyclopedic in nature. They should be used as an introduction to various topics.

Beck, A. et al. Excursions into Mathematics. New York: Worth, 1969.

Halmos, P. How to Write Mathematics. Providence, R.I.: American Mathematical Society, 1973.

Newman, J. R. The World of Mathematics. New York: Simon & Schuster, 1956-60.

Posamentier, A. and Stepelman, J. Teaching Secondary School Mathematics. Columbus, Ohio: Charles E. Merrill, 1981.

Schaaf, W. L. A Bibliography of Recreational Mathematics. National Council of Teachers of Mathematics, 1970-78.

- III. Classics: These are all-time bestsellers, in modern editions. Most primary sources are not suitable for student use: the material they cover can be taught more efficiently using modern methods. These are exceptions.

Archimedes. Works. Trans. T.L. Heath. Cambridge, 1897; rpt. New York: Dover.

Euclid. The Thirteen Books of Euclid's Elements. Trans. T.L. Heath. New York: Dover.

Gauss, K.F. Disquisitiones Arithmeticae. Trans. A. A. Clarke. New Haven: Yale University Press, 1966.

Heath, T. L. Diophantos of Alexandria. Cambridge: Cambridge University Press, 1910.

IV. Problem books: These contain problems on various topics and on different levels. Most contain solutions as well. Problems can often be used as a departure point for student projects.

Greitzer, S., ed. International Mathematical Olympiads. Washington, D.C.: The Mathematical Association of America, 1979.

Honsberger, R. Mathematical Gems. Washington, D.C.: The Mathematical Association of America, Vol. I, 1974. Vol. II, 1976.

----- Mathematical Morsels. Washington, D.C.: The Mathematical Association of America, 1979.

Honsberger, R., ed. Mathematical Plums. Washington, D.C.: The Mathematical Association of America, 1979.

Polya, G., and J. Kilpatrick. The Stanford Mathematics Problem Book. New York: Teachers College, 1974.

Porsventier, A., and C. Salkind. Selected Problems in Algebra. New York: Macmillan, 1964.

Rappaport, E., trans. Hungarian Problem Book I. New York: Random House, 1963.

----- Hungarian Problem Book II. New York: Random House, 1963.

Salkind, C. The Contest Problem Book. Washington, D.C.: The Mathematical Association of America, Vol. I, 1965, Vol. II, 1972, Vol. III, 1974.

*Shklarsky, D.O., Chentsov, N.M., and Yaglom, I.M. Selected Problems and Theorems in Elementary Mathematics. Moscow: Mir Publications (imported by Imported Publications, Inc., Chicago, 1979).

Shklarsky, D.O., et al. The USSR Olympiad Problem Book. San Francisco: W.H. Freeman, 1964.

V. Number Theory:

*Dudley, U. Elementary Number Theory. San Francisco: W.H. Freeman, 1978.

Hardy, G. H. and E.M. Wright. Introduction to the Theory of Numbers. Oxford: Oxford University Press, 1980.

Bicknell, M. and V.E. Hoggatt Jr., eds. Fibonacci's Problem Book. San Jose, Calif.: Fibonacci Association, San Jose State University, 1974.

Davis, P. J. The Lore of Large Numbers. New York: Random House, 1961.

*Ore, Oystein. Number Theory and Its History. New York: McGraw-Hill, 1948.

Sierpinsky, W. 250 Problems in Elementary Number Theory. New York: Elsevier, 1970.

Vinogradov, I.M. Elements of Number Theory. New York: Dover, 1954.

VI. Probability, Statistics, Game Theory.

Feller, W. An Introduction to Probability Theory and Its Applications. New York: John Wiley & Sons, 1968.

*Niven, I. Mathematics of Choice. Washington, D.C.: The Mathematical Association of America, 1975.

Packel, E. The Mathematics of Games and Gambling. Washington, D.C.: The Mathematical Association of America, 1981.

VII. Geometry

Altshiller-Court, N. College Geometry. New York: Johnson, 1927.

Coxeter, H.S. Introduction to Geometry. New York: John Wiley & Sons, 1969.

*Coxeter, H.S., and S. Greitzer. Geometry Revisited. Washington, D.C.: The Mathematical Association of America, 1975.

Golovina, L.I., and I.M. Yaglom. Introduction in Geometry. Moscow: Mir Publications 1979. Imported by Imported Publications, Chicago.

Hilbert, D., and S. Cohn-Vossen. Geometry and the Imagination. New York: Chelsea House, 1952.

Kazarinoff, M.D. Geometric Inequalities. New York: Random House, 1961.

Miller, L.H. College Geometry. New York: Appleton-Century-Crofts, 1957.

Modenov, P.S. and A.S. Parkhomenko. Geometric Transformations. New York: Academic Press, 1965.

Yaglom, I.M. Geometric Transformations. Washington, D.C.: The Mathematical Association of America, 3 vols. 1975.

VIII. Algebra

*Beckenback, E., and R. Bellman. An Introduction to Inequalities. New York: Random House, 1961.

Birkhoff, G. and S. MacLane. A Survey of Modern Algebra. New York: Macmillan, 1977.

Burnside, W.S. and A.W. Panton. Theory of Equations. New York: Dover, 1960.

*Grossman, I. and W. Magnus. Groups and Their Graphs. Washington, D.C.: The Mathematical Association of America, 1975.

Hall, H.S. and S.R. Knight. Higher Algebra. London: Macmillan, 1957.

IX. Analysis

Niven, I. Numbers, Rational and Irrational. New York: Random House, 1961.

Sawyer, W. W. What is Calculus About? New York: Random House, 1961.

Zippin, L. Uses of Infinity. New York: Random House, 1962.

X. Recreational Mathematics

Frohlichstein, J. Mathematical Fun, Games, and Puzzles. New York: Dover, 1962.

Kraitchik. Mathematical Recreations. New York: Dover, 1953.

*Schuh, F. The Master Book of Mathematical Puzzles and Recreations. New York: Dover, 1969.

XI. History of Mathematics

Bell, E.T. Development of Mathematics. New York: McGraw-Hill, 1945.

----- Men of Mathematics. New York: Simon and Schuster, 1937.

Dickson, L. History of the Theory of Numbers. New York: Chelsea House, 1975.

Kline, M. Mathematical Thought from Ancient to Modern Times. Oxford: Oxford University Press, 1972.

XII. Computer Science

Knuth, Donald L. The Art of Computer Programming. 3 vols. Reading, Mass.: Addison-Wesley, 1973, '74, '80.